FAA-E-2660
August 19, 1976

DEPARTMENT OF TRANSPORTATION
FEDERAL AVIATION ADMINISTRATION
SPECIFICATION

ATCRBS OPEN ARRAY ANTENNA
(FIVE-FOOT)

1. Scope

1.1 Scope. - The principal equipment specified herein is an antenna intended for deployment in the Air Traffic Control Radar Beacon System (ATCRBS). The antenna provides a conventional directional pattern, an integral side-lobe suppression (SLS) pattern, and a monopulse pattern. The directional pattern has a sharp underside cutoff to control ground lobing while the SLS pattern matches the phase center height of the directional pattern in order to assure that the lobing characteristics of the directional and SLS patterns are the same. The purpose of the monopulse pattern is to provide single-pulse estimates of the azimuthal positions of transponders within the main lobe of the directional pattern. This specification also includes a six-path rotary joint intended for use with the ATCRBS antenna.

2. APPLICABLE DOCUMENTS

The following specifications, orders, and standards, including all revisions and amendments in effect on the date of invitation for bids or requests for proposals, form a part of this specification and are applicable in their entirety unless otherwise specified herein.

FAA-D-2494	Technical Instruction Book Manuscripts: Electronic Equipment, Requirements for (All Parts)
FAA-G-1210	Provisioning Technical Documentation
FAA-G-1375	Spare Parts-Peculiar for Electronic, Electrical and Mechanical Equipment
FAA-G-2100	Electronic Equipment, General Requirements (All Parts and Supplement 4)
FAA-STD-012	Paint Systems for Equipment
FAA-STD-013	Quality Control Program Requirements
FAA HDBK 6040.10	Equipment Failure Handbook
DOT Order 1010.51A	Selection Order: U.S. National Aviation Standard for the Mark X (SIF) Air Traffic Control Radar Beacon System (ATCRBS) Characteristics

2.1 Precedence of documents. - When the requirements of the contract schedule, this document, or subsidiary applicable documents are in conflict, the following precedence shall apply. The contract schedule shall have precedence over all other documents. This document shall have precedence over all subsidiary applicable documents referenced herein. FAA documents have precedence over MIL documents.

2.2 Availability of documents. Copies of this specification and other applicable FAA and DOT specifications, standards, drawings, and the National Standard may be obtained from the Contracting Officer in the Federal Aviation Administration office issuing the invitation for bids or request for proposals. Requests should fully identify material desired, i.e., specification, standard, amendments, and drawing numbers and dates. Request should cite the invitation for bid, request for proposal, or the contract involved or other use to be made of the requested material.

Information on obtaining copies of Federal specifications and standards may be obtained from General Services Administration Offices in Atlanta; Auburn, Washington; Boston; Chicago; Denver; Fort Worth; Kansas City, Mo.; Los Angeles; New Orleans; New York; San Francisco; and Washington, D.C. Single copies of military specifications, handbooks, and standards may be requested by mail or telephone from the U.S. Naval Supply Depot, 5801 Tabor Avenue, Philadelphia, Pa., 19120; for telephone requests call 215-697-3321, 8:00 a.m. to 4:30 p.m., Monday through Friday. Not more than five items may be ordered on a single request. The applicable invitation for bid or contract number should be cited. Only latest revisions (complete with latest amendments) are available; slash sheets, such as MIL-E-1/306, must be individually requested. Request all items by document number.

3. REQUIREMENTS

3.1 Equipment and services to be furnished by the Contractor. The Contractor shall provide all necessary services and materials and shall design, fabricate, and test the equipments required by this document in the type and quantities and in accordance with the delivery schedule required by the contract. The Contractor shall also provide all necessary services and materials and shall prepare, reproduce, and provide reports, plans and instruction books as specified herein for delivery in accordance with the contract requirements. Any feature or item necessary for proper operation in accordance with the requirements of the contract shall be incorporated even though that item or feature may not be specifically described herein. Each equipment furnished by the Contractor shall be complete and shall be in accordance with all specification requirements.

The following equipments are to be supplied:

(a) ATCRBS Open-Array antennas to include, but not limited to:

- (1) Open array structure with associated support structure and installation mounting kits,
- (2) RF radiating elements,
- (3) RF feed network,
- (4) RF filters, and
- (5) Input connectors

(b) Rotary joint to include, but not limited to:

- (1) Housing and associated mounting interfaces;
- (2) Three each S-Band rotary paths with associated waveguide ports, connectors, covers, and terminations,
- (3) Three each L-Band rotary paths with associated connectors, caps, and terminations; and
- (4) Slip ring assembly.

In addition to the equipments listed above, the Contractor shall provide the items listed below:

(a) Test and maintenance equipment (para. 3.4),
(b) Instruction books and instruction book manuscript (para. 3.7),
(c) Equipment test plans and reports (para. 4.1 through 4.3), and
(d) Reliability and maintainability plans and reports (para. 4.4 and 4.5).

3.2 Definitions

3.2.1 Service conditions. The most severe operating condition is defined to be Environment III (Para. 1-3.2.23, FAA-G-2100/1) modified as follows:

Elevation: 0 to 12,000 feet above sea level

Relative humidity: 5% to 100% including condensation due to temperature changes.

Rain: Up to 60 mm/hr.

Hail: Up to 1 inch diamater hailstones at 60 ft./sec.

Barometric pressure: Up to 30.5 inches of mercury

Electromagnetic radiation: Up to 200,000 watts (peak) per square meter at duty cycles up to 0.2 percent at any frequency between 1250 and 1350 MHz or between 2700 and 2900 MHz.

The survival condition is defined to be the most severe operating condition with the winds to 125 knots.

3.2.2 Vertical. - A vertical line at any point is the line defined by the string supporting a nonmagnetic plumb bob. A vertical plane is any plane containing a vertical line.

3.2.3 Horizontal.- A horizontal plane is any plane for which the normal is a vertical line.

3.2.4 Elevation angle.- The elevation angle of any directed line originating at a point P is the smaller angle between the line and the horizontal plane through P as measured in the vertical plane which includes the line. The elevation angle is positive if the line is directed above the horizontal plane at point P and is negative if the line is directed below the horizontal plane at point P.

With reference to the antenna patterns specified herein, gains and patterns are specified and shall be measured along directed lines from the geometrical center of the antenna aperture to the point of observation (or the point at which the antenna range source is located). The elevation angle associated with any such specification or measurement shall be the corresponding elevation angle of this directed line if the antenna were mounted in its normal operating orientation with the underside -6dB point of the principal elevation plane sum pattern on the horizon (that is, on the horizontal plane passing through the geometrical center of the aperture).

3.2.5 Azimuth angle. - The azimuth angle of any directed line originating at a point P is the angle, measured in the horizontal plane through P, of the intersection of the vertical plane containing the line and the horizontal plane through point P. The angle of this intersection shall be measured positive clockwise (as viewed from above) from a specified or convenient reference direction (i.e., some other horizontal line through P).

With reference to the antenna patterns specified herein, gains and patterns are specified and shall be measured along directed lines from the geometrical center of the antenna to the point of observation (or the point at which the antenna range source is located). The azimuth angle associated with any such specification or measurement shall be the corresponding angle of the line of observation if the antenna were mounted in its normal operating orientation with the underside -6dB point of the principal elevation plane sum pattern on the horizon. All pattern azimuth angles are measured positive clockwise from the intersection of the principal elevation plane with the horizontal plane through the center of the array.

3.2.6 Principal elevation plane. With the antenna mounted in its normal operating orientation, the principal elevation plane is the vertical plane passing through the center of the aperture and the peak of the directional pattern.

3.2.7 Mean time between failures (MTBF). - All MTBFs specified herein are "specified mean time between failures", Θ_0, in the sense defined in paragraph 3.1 of MIL-STD-781. All MTBF requirements generated by the Contractor in response to the dictates of this specification shall also be "specified mean time between failures" as defined in MIL-STD-781.

3.2.8 Side-lobe suppression (SLS). SLS is a technique for suppression of transponder replies to interrogations by the side lobe radiation of the ATCRBS directional pattern. The interrogation mode RF pulse pair, P1 and P3, is radiated by the directional pattern. The P2 pulse radiated by the SLS pattern occurs at a specific time interval after the first interrogation pulse, P1, and at a fixed amplitude ratio with P1. The airborne radar beacon transponder contains circuitry for amplitude comparison and pulse spacing recognition of pulses P1 and P2 and suppresses replies whenever the amplitude of P2 exceeds the amplitude of P1.

3.2.9 Special tools, fixtures, and test equipments. - Any tool, fixture, or test equipment not listed for FAA Airport Surveillance Radar sites in either DOT Order 6200.4 (Test Equipment Management Handbook) or FAA Handbook 4630.2 (Standard Allowance of Supplies and Working Equipment for National Airspace System Facilities) is a special tool, fixture, or test equipment under the terms of this specification.

3.2.10 Peak and local peak gains. - The peak gain of the antenna is the maximum gain over all elevation and azimuth angles. The angle at which the peak gain occurs is defined to be the angle midway between the two points, one on either side and adjacent to the peak gain, at which the gain is 0.5 dB below the peak gain. A local peak is the point at which the antenna gain achieves a maximum over some restricted region (e.g., over all azimuth angles at some specified elevation angle). The angle at which a local peak occurs is defined to be the angle midway between the two points, one on either side and adjacent to the local peak, at which the gain is 0.5 dB below the local peak gain.

3.2.11 Pattern nulls. - A pattern null is a point at which the pattern gain achieves a minimum over some restricted region (e.g, over all azimuth angles at some specified elevation angle). The angle at which the null occurs is defined to be the angle midway between the two points, one on either side and adjacent to the null, at which the gain is 10 dB above the null gain. If the null depth is less than 20 dB, the angle at which the null occurs will be measured as described above except the two measurement points shall be at the gain level 2 dB above the null gain.

3.2.12 Phase center. - The phase center is the center of curvature of the wave front of the radiation for the pattern of interest as measured in some specified region.

3.2.13 Sum pattern. - The sum pattern is another name for the directional pattern. The directional pattern is the pattern for radiating ATCRBS interrogations and receiving conventional ATCRBS replies.

3.2.14 Difference pattern. - The difference pattern is another name for the monopulse pattern. The monopulse pattern may be used in conjunction with the sum pattern to estimate the azimuth angles of transponders within the main lobe of the directional pattern.

3.2.15 Error pattern. - The error signal is defined as the amplitude of the diffrence signal divided by the amplitude of the sum signal. The difference signal is the RF return from the difference pattern (available at the difference port of the antenna) and the sum signal is the RF return at the sum port. The error pattern is the graph of the error signal versus the azimuth angle of the far-field RF source generating the sum and difference signals.

3.2.16 SLS pattern. - The SLS pattern radiates the side-lobe suppression (P2) pulses.

3.2.17 Side lobe. - A side lobe is any radiation lobe (local maximum) in the front hemisphere (within 90 degrees azimuth of the principal elevation plane) other than the intended lobe (main lobe). Beam shoulders (local maxima immediately adjacent to the main lobe which are less than 1 dB high as measured from the peak of the shoulder to the base of the null between the shoulder and the main lobe) are considered a part of the main lobe and hence are not side lobes.

3.2.18 Back lobe. Any radiation lobe in the back hemisphere.

3.2.19 Pattern slope. - The sum, difference, or SLS pattern slope measured along a prescribed angular coordinate at some reference point is defined as follows. Let G(0) be the gain (in dB) of the pattern at the reference point. Let E1 be the angle (along the prescribed coordinate) nearest the reference point at which the gain is (G(0) + 1 dB) and E2 be the angle nearest the reference point at which the gain is (G(0) - 1dB). Then the slope of the pattern at the reference point is defined to be the slope of the straight line passing through the two points (E1, (G(0) + 1dB)) and (E2, (G(0) - 1dB)).

The slope of the error pattern for positive (negative) azimuth angles is defined as the slope of the straight line passing thru the error pattern at zero degrees azimuth and the positive (negative) azimuth angle at which the sum pattern is 2 dB below the local peak of the beam.

3.2.20 Relative field strength. - The relative field strength is the field strength relative to the local peak of the pattern.

3.2.21 Standard ATCRBS reply pulse. - For the purposes of this specification, the standard ATCRBS reply pulse has a rise time of between 50 and 60 nanoseconds (from the 10 to 90 percent amplitude points), a fall time of between 50 and 60 nanoseconds (from the 90 to 10 percent amplitude points), and a pulse duration of between 300 and 350 nanoseconds as measured between the 90 percent amplitude points on the leading and trailing edges. The pulse amplitude is constant to within 10% of the peak amplitude over the pulse duration. The RF carrier of the pulse is at any frequency between 1085 and 1095 MHz.

3.2.22 Post-hybrid phase angle. - The post-hybrid phase angle is the phase angle of the difference signal measured with respect to the phase angle of the sum signal.

3.3 Performance requirements. The requirements described below shall be met under the service conditions of paragraph 3.2.1 with continuous unattended operation.

3.3.1 Antenna electrical requirements. - Each antenna shall provide separate and independent sum, difference, and SLS ports (connectors) so that it is possible to simultaneously transmit on all three patterns and to simultaneously receive on all three patterns. Each antenna shall have exactly 3 input-output connectors, 1 each for sum, difference, and SLS. RF switching shall not be employed. The sum pattern shall have low side lobes and shall have a null (para. 3.2.11) on the principal elevation plane over -2 to +40 deg. elevation. The SLS pattern shall generally cover the side lobes of the sum pattern.

Each pattern and relevant combination of patterns shall meet the requirements below. All antenna pattern characteristics specified refer to one-way relative power patterns of completely assembled antennas. Except as otherwise noted herein, the sum and SLS patterns shall have the prescribed characteristics at all frequencies over the band from 1026.5 to 1033.5 MHz (designated herein as 1030 $\pm$ 3.5 MHz) and at all frequencies over the band from 1085 to 1095 MHz (designated herein as 1090 $\pm$ 5 MHz). The difference pattern shall provide the prescribed characteristics over 1090 $\pm$ 5 MHz.

3.3.1.1 Elevation radiation patterns. -

3.3.1.1.1 Directional (sum) pattern. - The sum pattern shall have the following characteristics along the principal elevation plane. The relative field strength at 6 deg. elevation shall be within 1.0 dB of the peak of the beam. The relative field strength shall decrease monotonically with decreasing elevation angle from 6 deg. elevation to the point at which the pattern is 16 dB below the peak of the beam (the -16 dB point). The -16 dB point shall occur at an angle above -3.5 degrees elevation.

The slope of the pattern at any point between zero degrees elevation and the -16 dB point shall be no less than 1.8 dB per degree.

At all elevation angles from the -16 dB point to -14 degrees elevation, the relative field strength shall not exceed -12 dB. At all elevation angles from -14 degrees to -26 degrees, the relative field strength shall not exceed -14 dB. At all elevation angles below -26 degrees, the relative field strength shall not exceed -18 dB.

The field strength shall remain constant to within 4.5 dB peak to valley from 5 degrees to 32 degrees elevation, shall be constant to within 6.5 dB peak to valley from 5 degrees to 40 degrees elevation over 1030 ± 3.5 MHz, and shall be constant to within 11 dB peak to valley from 5 degrees to 40 degrees elevation over 1090 ± 5 MHz.

Above 40 degrees elevation the pattern shall decrease with the relative field strength at all angles above 50 degrees at least 16 dB below the peak of the beam, the relative field strength at all angles above 60 degrees at least 20 dB below the peak of the beam, and the relative field strength at all angles above 70 degrees at least 25 dB below the peak of the beam.

3.3.1.1.2 Monopulse (difference) pattern. - The difference pattern, in azimuth, shall possess a null at the principal elevation plane over the range of elevation angles between -2 and +40 deg. so that there are two local pattern peaks one on either side of and adjacent to the principal elevation plane. The conical-cut elevation pattern passing through either of these local difference pattern peaks at zero degrees elevation shall have the following characteristics when the antenna is mounted in its normal operational orientation. The shape of the relative field strength of the difference pattern shall be within ± 1 dB of the measured 1090 MHz sum principal elevation plane pattern over the range of elevation angles from -1 to +30 degrees and shall be within ± 2 dB from -1 to 40 deg. elevation. The relative field strength shall decrease monotonically with decreasing elevation angle from 5 degrees elevation to the point at which the pattern is 16 dB below the local peak (the -16 dB point). The slope of the pattern at any point between zero degrees elevation and the -16 dB point shall be no less than 1.8 dB per degree. The -16 dB point shall be above -4 degrees elevation.

At all elevation angles from the -16 dB point to -14 degrees elevation, the relative field strength shall not exceed -11 dB. At all elevation angles from -14 degrees to -26 degrees, the relative field strength shall not exceed -13 dB. At all elevation angles below -26 degrees, the relative field strength shall not exceed -17 dB.

Above 40 degrees elevation the pattern shall decrease with the relative field strength at all angles above 50 deg. less than -15 dB, the relative field strength at all angles above 60 deg. less than -19 dB, and the relative field strength at all angles above 70 deg. less than -24 dB.

3.3.1.1.3 SLS pattern. - At any azimuth angle for which the gain of the SLS pattern at +6 degrees elevation is within 8 dB of the peak of the SLS pattern at +6 degrees elevation, the SLS elevation pattern shall meet the following requirements when the antenna is mounted in its normal operational orientation. At 6 degrees elevation, the relative field strength shall be between 0 and -2 dB and shall decrease monotonically with decreasing elevation angle to a level of -12 dB (the -12 dB point). The -12 dB point shall lie above -4 degrees elevation. From +6 to -2 degrees elevation, the shape of the SLS pattern shall be the same as that of the principal elevation plane sum pattern to within ± 1.5dB. The relative field strength at zero degrees elevation shall be -6 ±1.5 dB and the pattern slope at all elevation angles between zero degrees and the -12 dB point on the underside of the pattern shall be at least 1.6 dB/degree.

The underside side lobes of the elevation pattern shall be at least 10 dB below the local peak of the pattern at all elevation angles below the underside -12 dB point.

The SLS pattern shall cover the sum pattern side-lobe and back-lobe radiation at elevation angles from -2 to +70 degrees as specified in para. 3.3.1.2.4. In addition, at any azimuth angle outside the -20 dB beamwidth of the directional pattern at zero degrees elevation for which the gain of the SLS pattern at +6 degrees elevation is within 8 dB of the peak of the SLS pattern at +6 degrees elevation, the SLS elevation pattern shall meet the following requirements. At all elevation angles from the underside -12 dB point to -70 degrees, the underside side-lobe levels shall be at least 8 dB below the pattern level at the corresponding positive elevation angle.

At any azimuth angle within 10 degrees of the principal elevation plane for which the gain of the SLS pattern at +6 degrees elevation is within 8 dB of the peak of the SLS pattern at +6 degrees elevation, the RF phase difference between the principal elevation plane sum pattern and the SLS elevation pattern shall fluctuate less than 20 degrees peak to valley over elevation angles between +3 and -1 degrees.

3.3.1.2 Azimuth radiation patterns. - All azimuth radiation patterns are defined as field strength versus azimuth angle at a constant elevation angle.

3.3.1.2.1 Directional (sum) pattern. - At zero degrees elevation, the sum pattern main lobe shall have a half-power width of 2.35 ± 0.25 degrees, a width at 10 dB below the local peak of the pattern of less than 4.5 degrees, and a width at a relative field strength of -20 dB not to exceed 7 degrees. Over the range of elevation angles from -2 to +40 degrees, the -3 dB (-10 dB) beamwidth shall not vary by more than -10% to +15% from the -3 dB (-10 dB) beamwidth at zero degrees elevation divided by the cosine of the elevation angle. Over the range of elevation angles from zero to +40 degrees, the -20 dB beamwidth shall not vary by more than -10% to + 35 % from the -20 dB beamwidth at zero degrees elevation divided by the cosine of the elevation angle.

At all elevation angles below -2 deg and at all elevation angles above +40 deg, all side lobes and back lobes shall be at least 28 dB below the peak of the sum pattern. At all elevation angles between -2 and +40 deg, all side lobes and back lobes shall be at least 26 dB below the local peak of the sum pattern. No side lobe or back lobe level is required to be more than 29 dB below the peak of the sum pattern. That is, whenever a side lobe or back lobe specification based upon the local peak of the pattern requires that the side lobe or back lobe be more than 29 dB below the peak of the pattern, it shall be sufficient for that side lobe or back lobe to be 29 or more dB down based upon the peak of the pattern.

3.3.1.2.2 Monopulse (difference) pattern. - At all elevation angles from -2 to +40 degrees, the difference pattern shall possess two peaks one on either side of and immediately adjacent to the principal elevation plane. These pattern peaks are referred to as the difference pattern peaks in the requirements below. At any elevation angle, the higher of the two difference pattern peaks is the local peak of the difference pattern at that elevation angle.

At all elevation angles from -2 to +40 deg, the following requirements shall be met. Each difference pattern peak shall occur within (2.5/cos y, y = elevation angle) degrees of the principal elevation plane. The relative field strength of the weaker difference pattern peak shall not be less than -1 dB. As the azimuth angle increases from the difference pattern peak at the negative azimuth angle, the relative field strength shall decrease monotonically to a null (the difference pattern null) and shall then increase monotonically to the difference pattern peak at the positive azimuth angle. The null depth shall be at least 28 dB below the local peak of the difference pattern at +6 deg elevation and shall be at least 16 dB below the lower of the two difference pattern levels at the sum pattern cross-over points. On both sides of the principal elevation plane, with equal excitation applied at the sum and difference ports of the antenna, the field strength of the difference pattern shall cross over the field strength of the sum pattern at a point -3 dB ± 0.5 dB below the local peak of the sum pattern.

At all elevation angles below -2 degrees and above +40 degrees, all side-lobe and back-lobe levels shall be at least 26 dB below the local peak of the difference pattern at 6 deg elevation. At all elevation angles from -2 to +40 deg., all side lobes and back lobes shall be at least 24 dB below the local peak of the difference pattern. No side lobe or back lobe is required to be more than 27 dB below the peak of the difference pattern at 6 deg elevation. That is, whenever a side lobe or back lobe specification based upon the local peak of the difference pattern requires that the sidelobe or back lobe be more than 27 dB below the peak of the pattern at 6 degrees elevation, it shall be sufficient for that side lobe or back lobe to be 27 or more dB down based upon the difference pattern peak at 6 degrees elevation.

3.3.1.2.3 Error pattern. - The error pattern, as plotted from the antenna sum and difference signal characteristics over 1090 ±5 MHz, shall meet the following requirements.

At all elevation angles from -1 to +5 degrees, the magnitude of the slope of the error pattern at both positive and negative azimuth angles shall be within 5 percent of the slope of the error pattern for positive azimuth angles at zero degrees elevation. At all elevation angles from +5 to +20 degrees (+20 to +40 degrees), the magnitude of the slope of the error pattern at both positive and negative azimuth angles shall be within 10 (15) percent of the product of the slope of the error pattern for positive azimuth angles at zero degrees elevation and the cosine of the elevation angle. All antennas shall have the same error pattern slope for positive azimuth angles at zero degrees elevation to within ±10% of a Contractor-specified nominal value.

At all elevation angles between -1 and +40 deg and all positive (negative) azimuth angles between the -1 dB point and the -10 dB point of the sum pattern main lobe, the post-hybrid phase angle shall be zero (180) degrees to within plus or minus the phase error bounds specified below. From -1 to +5 degrees elevation, the phase error bound shall be 10 degrees. From +5 to +10 degrees elevation, the phase error bound shall be 20 degrees. From +10 to +40 degrees elevation, the phase error bound shall be 30 degrees.

3.3.1.2.4 SLS pattern. - The implementation of the SLS pattern shall include one radiating system which provides the major portion of the SLS energy for the hemisphere in front of the antenna and a separate radiating system (the back-fill radiator) which provides the major portion of the SLS energy behind the antenna. The Contractor shall define a nominal amplitude ratio and phase difference for driving these two radiating systems to meet the requirements below. In addition, it shall be possible to reduce the amplitude of the SLS radiation in the front hemisphere by 3, 6 and 10dB relative to the nominal amplitude ratio by inserting standard coaxial attenuators and/or couplers into a single signal path in the antenna. The addition of the attenuators/couplers shall not change the phase length of the signal path by more than ±5 degrees. It shall also be possible to change the phase of the back-fill radiator relative to its nominal value by up to 360 deg in steps of 45 ±10 deg. by replacing a single cable in the antenna.

It shall be possible to make all phase adjustments at each of the four specified attenuation levels (nominal amplitude ratio or front SLS radiation reduced by 3, 6, or 10 dB). All components required for making the level and phase adjustments described above shall be supplied with each antenna. The power rating of the attenuators and power dissipation provisions shall be sufficient to handle 5 Kw peak at a one percent duty cycle at the SLS input of the antenna. The antenna shall include provisions for mounting all necessary components and it shall be possible to make any level/phase adjustment on a normally installed antenna in thirty minutes or less. The requirements of para. 3.3.1.1.3 shall be met with the nominal amplitude ratio and phase difference defined by the Contractor and may not be met when these nominal values are perturbed as described above.

With the nominal front-to-back amplitude ratio and phase difference defined by the Contractor, the SLS pattern shall have the following characteristics over 1030 ± 3.5 MHz when equal excitation is applied at the sum and SLS ports of the antenna. At all elevation angles from -1 to +20 degrees (+40 to +70 degrees), the SLS field strength shall exceed the 1030 MHz sum pattern field strength by at least 4dB (0 dB) at all azimuth angles outside the main lobe of the sum pattern. From +20 to +40 deg. elevation, the SLS field strength shall exceed the 1030 MHz sum pattern field strength at all azimuth angles for which the 1090 MHz sum pattern side lobes or back lobes exceed -33 dB relative to the peak of the 1090 MHz sum pattern. If at any elevation angle between +20 and +40 deg there is an interval, in azimuth, over which the SLS field strength does not exceed the field strength of 1030 MHz sum pattern side lobes or back lobes, then (a) there shall be at most two such intervals at that elevation angle over 360 deg. in azimuth, (b) the angular extent of all such intervals shall be less than 2.0 deg in azimuth, and (c) the azimuth at which any such interval occurs shall be more than 60 degrees from the principal elevation plane.

Over 1030 ± 3.5 MHz and 1090 ± 5 MHz, the SLS pattern shall be constant to within 10 dB peak to valley over 90 percent of any 360 deg azimuth pattern between -1 and +40 deg elevation.

The SLS pattern shall have the following characteristics over 1030 ± 3.5 MHz as referenced to the sum pattern at the same frequency when equal excitation is applied at the sum and SLS ports of the antenna. At all elevation angles between -2 and +30 deg, the SLS pattern shall cross the sum pattern main lobe at two points one on either side of the principal elevation plane. Each of these cross-over points shall be between 15 and 21 dB below the local peak of the sum pattern. At all elevation angles between +30 and +40 deg. the sum pattern cross-over points shall both be between 12 and 21 dB below the local peak of the sum pattern. At any elevation angle from -1 to +3 deg, the two sum pattern cross-over points shall have field strengths which are the same to within 3 dB. At all elevation angles from +3 to +40 deg, the two sum pattern cross-over points shall have the same field strengths to within 5 dB.

At all elevation angles from -1 to +40 degrees, the SLS field strength at all azimuth angles between the sum pattern cross-over points shall not exceed the level of the higher of the two cross-over points. At all elevation angles from -1 to +30 degrees, the slope of the SLS pattern (in azimuth) at the cross-over point which occurs at the negative azimuth angle shall be less than -2 dB/deg (greater than 2 dB/deg in magnitude) and the slope of the SLS pattern (in azimuth) at the cross-over point which occurs at the positive azimuth angle shall be greater than 2dB/deg. At all elevation angles from -1 to +30 degrees, the SLS field strength on the principal elevation plane shall be at least 4dB below the SLS field strength at the lower of the two cross-over points at the same elevation angle.

3.3.1.3 Cross-polarized radiation. - The radition from the antenna with any port (sum, difference, or SLS) driven shall be vertically polarized when the antenna is mounted in its normal operational configuration. The cross-polarized (horizontal) components of the radiation shall meet the following requirements at all elevation angles from -2 to +40 deg. The cross-polarized radiation from the sum and the difference patterns shall be more than 25 dB below the local peak of the respective pattern. The cross-polarized radiation from the SLS pattern shall be more than 20 dB below the local peak of the SLS pattern. In no case is the cross-polarized radiation of a pattern required to be more than 30 dB below the peak of that pattern. Whenever a cross-polarized radiation specification based upon the local peak of the pattern requires that cross-polarized radiation be more than 30 dB below the peak of the pattern, it shall be sufficient for the cross-polarized radiation to be 30 or more dB below the pattern peak.

3.3.1.4 Gain. - The peak gain of the directional (sum) pattern shall be a minimum of 21 dB relative to a lossless isotropic radiator.

3.3.1.5 Input voltage standing wave ratio. - At all three antenna ports (sum, difference, and SLS), the input VSWR shall not exceed 1.5:1 referenced to a 50 ohm line.

3.3.1.6 Power handling capacity. - The antenna (less the attenuators of para 3.3.1.2.4) shall be capable of continuously radiating without breakdown a peak pulse power of 15,000 watts at a 1.0 percent duty cycle when driven at any port (sum, difference, or SLS).

3.3.1.7 Operating frequency. - The antenna shall operate over the frequency range 1030 ± 3.5 MHz and the frequency range 1090 ± 5 MHz as specified herein.

3.3.1.8 Pulse shape. - The antenna shall meet all requirements specified herein when fed by pulses (P1, P2 and P3) with the pulse shape characteristics specified in Section 2.4 of DOT Order 1010.51A.

3.3.1.9 Pulse distortion. - At any elevation angle between -2 and +5 degrees, the sum and difference patterns shall meet the following requirements over 1090 ±5 MHz when the received pulsed signal originates from a source located at either azimuth angle corresponding to a relative field strength of -3 dB in the sum pattern. When the pulsed signal is a standard ATCRBS reply pulse with rise and fall times of less than 55 nanoseconds, the rise and fall times of pulses received at the sum and difference ports shall be less than 60 nanoseconds. In addition, the sum and difference pulses shall be flat to within -15% of their respective peak amplitudes over the pulse duration (between the 90% amplitude points on the leading and trailing edges). Between the 50% and 90% amplitude points of the sum pattern output pulse, on both the leading and the trailing edges, the shape of the difference pattern output pulse shall be the same as that of the sum pattern output pulse to within ± 10% of the sum pattern output pulse. Between the 90% amplitude points on the leading and trailing edges of the sum pattern output pulse, the shape of the difference pattern output pulse shall be the same as that of the sum pattern output pulse to within ±5% of the sum pattern output pulse.

3.3.1.10 Pattern squint and skew. - The following requirements shall be met by the sum pattern over 1030 ± 3.5 MHz and by both the sum and the difference patterns over 1090 ± 5 MHz when the array is mounted in it normal operational orientation. Over all elevation angles from -1 to +10 degrees, the local peak of the sum pattern shall lie within 0.2 degrees of the principal elevation plane. Over all elevation angles from +10 to +40 degrees, the local peak of the sum pattern shall lie within 0.3 degrees of the principal elevation plane. The null of the difference pattern shall lie within ± 0.1 degrees, ± 0.2 degrees, and ± 0.3 degrees of the principal elevation plane over the elevation angles of -1 to + 3, +3 to +10, and +10 to +40 degrees respectively.

With the array antenna in its normally installed configuration on the ASR antenna, the principal elevation plane of the array shall be aligned with the principal elevation plane of the ASR antenna to within ± 0.2 degrees in azimuth for all angles of array tilt.

<u>3.3.1.11 Input Connectors</u>. - A type HN weatherproof male coaxial connector in accordance with MIL-C-3643 shall be used for each RF input/output connector. These connectors shall be labelled "Directional", "Monopulse", or "SLS" as appropriate. The directional and SLS connectors shall be fitted with weatherproof covers. The monopulse connector shall be fitted with a weatherproof termination.

<u>3.3.2 Antenna mechanical requirements</u>. - In order to minimize the forces and torques applied to the ASR antenna system that will support the antenna specified herein, the antenna shall be an open array construction designed to reduce wind resistance. The major mechanical components of the antenna shall be <u>the array structure</u> which supports the radiating elements and houses the necessary feed networks, <u>the support structure</u> which interfaces with the array structure and the ASR antenna to hold the array structure in place, and the <u>mounting installation kits</u> which include all brackets and miscellaneous items of hardware necessary to interface and fasten the array structure and support structure to the ASR antenna. The back-fill radiator may mount on either the array structure or the support structure.

The array structure and/or support structure shall incorporate foot pads and hand holds in the areas where technicians will be required to climb onto and/or stand on the installed antenna for purposes of antenna maintenance. Provisions for securing safety belts shall be included in those areas where technicians will be required to work.

All hardware necessary for completely installing the antenna on either an ASR-8 or an ASR-4/5/7 shall be supplied with each antenna. The array structure and support structure shall be universal in the sense that these items shall be identical between ASR-8 and ASR-4/5/7 installations. Two each mounting installation kits shall be supplied with each antenna. One kit shall contain all items necessary to facilitate an ASR-8 installation and the second kit shall contain all items necessary to facilitate an ASR-4/5/7 installation. The ASR-4, ASR-5, and ASR-7 reflectors are identical so that the same mounting installation kit can be used for each of the three. The ASR-4, ASR-5, and ASR-7 radars are referred to collectively herein as the ASR-4/5/7 radar.

The array structure shall be packed and shipped in two sections, each comprising approximately one half of this structure, for assembly in the field. The support structure shall be packed and shipped separately. All items required for completely assembling the antenna in the field shall be properly designed and marked, without ambiguity, so as to ensure compliance with all requirements of this specification when so assembled.

3.3.2.1 Dimensional and weight restrictions. - The overall dimensions of the array structure shall not exceed 65 inches high by 27 feet long by 18 inches deep. The complete antenna shall weigh less than 550 pounds. No part of the antenna will extend more than 8 inches in front of the front top edge of the ASR reflector when the ASR tilt indicator is set at zero degrees and the array is tilted so that the -6 dB point on the underside of the sum principal elevation plane pattern is on the horizon.

The vertical cross section of the antenna, as defined by the horizontal projection of the installed antenna onto a vertical plane normal to the projection, shall meet the following requirement. The cross section at all angles of antenna rotation and tilt shall not exceed 55 square feet without ice and shall not exceed 85 square feet with the antenna completely coated with ½ inch of radial ice.

With the array structure and back-fill radiator at zero degrees tilt (para. 3.3.2.3), the horizontal cross section of the antenna as defined by the vertical projection of the installed antenna onto a horizontal plane, shall be less than 60 square feet with the antenna completely coated with ½ inch of radial ice.

3.3.2.2 Finish. - Except for the necessary masking of parts such as electrical connectors, all exterior surfaces shall be finished in accordance with FAA-STD-012. Paint system FS-3, ZS-3, or AS-3 shall be used. The finish coat shall be aviation orange (color No. 12197) in accordance with Federal Standard 595. All horizontal members of the array structure and the support structure which will not support the full weight of personnel working on the antenna shall be stenciled "No Step" using black lettering at least 1-inch high. The Contractor shall ensure that the exterior finish selected does not interfere with the electrical performance of the antenna.

3.3.2.3 Tilt provisions. - The support structure and/or the array structure shall include provisions for tilting the array structure so that the -6 dB point on the underside of the principal elevation plane sum pattern can be raised 6 degrees and lowered 5 degrees with respect to the horizontal when the existing mounting pads at the top of the ASR reflector are horizontal. The back-fill radiator shall be independently tiltable so that the -6 dB point on the underside of the principal elevation plane pattern of the back-fill radiator can be raised 3 degrees and lowered 3 degrees with respect to the horizontal when the elevation angle of the -6 dB point on the underside of the principal elevation plane sum pattern is anywhere between -2 and +2 degrees.

The array structure is at zero degress tilt when the -6 dB point on the underside of the principal elevation plane sum pattern is on the horizon.

The back-fill radiator is at zero degrees tilt when the -6 dB point on the underside of the principal elevation plane back-fill radiator pattern is on the horizon. When the array structure (back-fill radiator) is at zero degrees tilt, the mechanical tilt of the array structure (back-fill radiator) shall be the same for all antennas to within ± 0.5 degree. At installation, it shall be possible to mechanically adjust the array structure and the back-fill radiator for zero degrees tilt with an accuracy of ± 0.6 degrees without the use of any electrical measurements. The accuracy with which subsequent tilt adjustments can be made shall be ± 0.2 degrees.

The tilt mechanisms for the array structure and the back-fill radiator shall include tilt indicators with adjustable scales. The tilt indicators shall be graduated in 0.2 deg increments. The scale of the array structure tilt indicator shall be adjustable to the negative of the ASR tilt indicator reading so that the elevation angle, with respect to the horizon, of the zero-degree point on the principal elevation plane of the sum pattern can be computed as the sum of the ASR and array structure tilt indicator readings. The scale on the back-fill radiator tilt indicator shall be similarly adjustable so that the elevation angle, with respect to the horizontal, of the -6 point on the underside of the principal elevation plane of the back-fill radiation pattern, can be computed as the sum of up to three tilt indicator readings (i.e., the readings of the ASR, array structure, and back-fill radiator indicators). Tilt angles are positive upwards.

The tilt mechanisms for the array structure and the back-fill radiator shall provide positive control of tilt angle throughout the tilt adjustment procedure and shall include provisions for positively locking the respective radiating systems at the desired tilt angles. The tilt mechanisms shall be accessible, and easily operable without special tools, by one technician.

3.3.2.4 Structural requirements. - The structural design of the antenna shall ensure that under the most severe operating conditions with rotational speeds up to 15 rpm, and under the survival conditions of para. 3.2.1, the safety factors (based on stress levels) in the structure shall be a minimum of 2.0.

The deflections of the array as mounted on a rigid ASR reflector under the most severe operating conditions, with rotational speeds up to 15 rpm, shall satisfy the following requirements with respect to the nominal array structure contour defined by the Contractor. The deflections of the tips of the array measured in the horizontal plane shall be less than 3/4 inch, and the deflections in the horizontal plane at a distance midway between the vertical center line of the array and the tips of the array shall be less than ½ inch. The horizontal deflection of the array at its vertical center line shall be less than 3/8 inch. The elevation angles of the -6 dB points on the underside of the sum and back-fill radiation patterns on the respective principal elevation planes shall vary less than 0.5 deg and the peak of the sum pattern shall deflect less than 0.3 degree in azimuth.

3.3.2.5 Mechanical restrictions. A minimum of machining of the ASR reflector structure shall be required for the installation of the antennas. The existing mounting plates at the top of ASR reflectors (Fig. 1) shall be employed to support the principal vertical loads.

The loads imposed on the ASR antenna group under maximum operating conditions at 12.5 rpm, and under survival conditions with winds limited to 110 knots, shall meet the following requirements. The minimum safety factor (based on stress levels) in the ASR reflector structure shall be greater than 1.5. Under maximum operating conditions at 12.5 rpm, the deflections of the ASR reflector (with its ice and wind load) from the static curvature shall not exceed $\pm \frac{1}{2}$ inch at the center and ± 1 inch at the tip and the deviation in radial distance from the focal point to the top of the reflector in the symmetrical center line plane through the focal point shall not exceed $\pm 3/8$ inch. ASR pedestal bearing stresses shall not exceed 90% of the stress at which detectable brinelling occurs. In addition, under maximum operating conditions at 12.5 rpm, the pedestal peak and average drive requirements shall not exceed levels 60% above those required for rotating the ASR reflectors with a standard FAA Hogtrough antenna under the same environmental conditions.

3.3.3 Filter electrical requirements. - Each antenna shall be supplied with a matched pair of fixed-tuned low-pass RF filters. The purpose of each filter shall be to attenuate incoming RF energy (such as may be received from a colocated radar) a minimum of 50 dB over the range of 1280 to 11,000 MHz. The attenuation to transmitter RF energy throughout the range of 1026.5 to 1033.5 MHz shall not exceed 0.5 dB and the attenuation to received RF energy throughout the range of 1085 to 1095 MHz shall not exceed 1.0 dB. The input VSWR of each filter over the frequency range from 1026.5 to 1033.5 MHz shall be less than 1.25:1 and over the frequency range from 1085 to 1095 MHz shall be less than 1.5:1. Each filter shall be capable of continuously transmitting, without breakdown, a peak power of 15,000 watts at a 1.0 percent duty cycle at any frequency between 1026.5 and 1033.5 MHz. Each filter shall be capable of withstanding the electromagnetic radiation environment of para. 3.2.1 when connected to either the sum port or difference port of the array antenna.

Each matched pair of filters shall meet the following requirements over 1085 to 1095 MHz. The phase shift through the filters shall be the same to within 10 degrees and the insertion losses shall the same to within 0.2 dB. When a standard ATCRBS reply pulse with rise and fall times of less than 55 nanoseconds is applied to either filter, the rise and fall times of the output pulse shall be less than 60 nanoseconds. In addition, the output pulses shall be flat to within -15% of the peak amplitude over the pulse duration (i.e., between the 90% amplitude points on the leading and trailing edges of the pulse). Between the 50% and 90% amplitude points on the leading and trailing edges of the output pulses of the matched filter pair, the two pulse shapes shall be same within ±10% of the output pulse shape of one of the filters. Between the 90% amplitude points on the leading and trailing edges of the output pulses, the two pulse shapes shall be the same to within ±5% of the output pulse shape of one of the filters.

A series HN weatherproof female coaxial connector shall be provided at the antenna end of each filter and a series HN weatherproof male coaxial connector shall be provided at the other end. HN connectors shall be in accordance with MIL-C-3643.

3.3.4 Filter mechanical requirements. - Each filter shall be as small and compact as practicable. The female connector of one filter shall connect directly to the sum port connector of the antenna without the use of any intervening cable or adapter. The other filter of the matched pair shall connect directly to the difference port connector of the antenna without the use of any intervening cable or adapter. The antenna shall include provisions for mechanically supporting the filters (when connected as described above) in accordance with the environmental conditions of para. 3.2.1. Provisions for adequately supporting the RF cables that connect to the filters will also be included. These RF cables may be either RG-218 or RG-214 and the Contractor shall provide means of supporting both type cables at both filters.

The filters and associated hardware shall be finished in accordance with para. 3.3.2.2.

3.3.5 Rotary joint electrical requirements. - The Contractor shall provide rotary joints in the quantities prescribed by the contract. Each rotary joint shall meet the electrical requirements below. Each rotary joint shall have 6 RF sections (channels) three of which shall be utilized by the ASR and three of which shall be utilized by the ATCRBS array antenna. All sections shall be constructed with non-contacting joints. All sections of the rotary joint shall transfer energy without change of polarization through 360 deg rotation of the joint. The isolation between all sections of the joint shall be no less than 50 dB.

The rotary joint shall meet the following requirements throughout 360 degrees of rotation.

	Section 1	Section 2&3	Section 4, 5, &6
Frequency range	2.7.-2.9 GHz	2.7-2.9 GHz	1026-1034 MHz 1085-1095 MHz
Peak power:			
Unpressurized	1.25 Mw	1 Kw	5 Kw
Pressurized	2.50 Mw	N/A	N/A
Duty cycle	0.0015	0.0015	0.01
Maximum VSWR	1.2:1	1.2:1	1.2:1
VSWR change over 360° rotation	0.05	0.05	0.07
Insertion loss	0.2 dB max	#2,0.5 dB max #3,0.75 dB max	0.75 dB max (Note 1)
Phase shift change over 360° rotation	5 deg.	5 deg.	5 deg. (Note 1)
Input-output connectors	Waveguide	#2, Waveguide #3,50 ohm coaxial cable	50 ohm coaxial cable

NOTE 1: Throughout the frequency range from 1026.5 to 1033.5 MHz, the insertion loss of sections 4 and 5 shall be the same to within 0.1 dB and the phase shift through these two sections shall be same to within 5 degrees. Throughout the frequency range from 1085 to 1095 MHz, the insertion loss of sections 4 and 6 shall be the same to within 0.1 dB and the phase shift through these two sections shall be the same to within 5 degrees. Sections 4 and 6 shall meet the following additional requirements when a standard ATCRBS reply pulse having rise and fall times less than 55 nanoseconds is transmitted through these sections. The rise and fall times of the output pulses shall be less than 60 nanoseconds and the output pulses shall be flat to within -15% of their respective peak amplitudes over the pulse duration (that is, between the 90% amplitude points on the leading and trailing edges). Between the 50% and 90% amplitude points on the leading and trailing edges of the output pulses, the pulse shapes in sections 4 and 6 shall be the same to within ±10% of the output pulse amplitude of one of the two sections. Between the 90% amplitude points on the leading and trailing edges of the output pulses, the two pulse shapes shall be the same to within ± 5% of the output pulse amplitude of one of the two sections.

All connectors and waveguide ports supplied on the rotary joint shall be the same as those currently employed on ASR-8 rotary joints. The rotary joint will be supplied with weatherproof covers on all connectors and waveguide ports. Section 2,3, and 6 will be supplied with weatherproof RF terminations installed on the stationary input ports. The input and output connectors of section 4 shall be labelled "Beacon Directional". The input and output connectors of section 5 shall be labelled "SLS". The input and output connectors of section 6 shall be labelled "Monopulse". The input and output ports of section 1 shall be labelled "High Power". The input and output ports of section 2 shall be labelled "Low Power".

A slip ring assembly providing 12 each one-wire circuits each capable of handling 120 volts at 5 amps, 60 Hz, shall be provided as an integral part of the rotary joint. The assembly shall be reliable and easily adjustable with a useful slip ring brush life of at least 25,000 hours operation without adjustment. The leakage resistance between adjacent slip ring circuits shall be 100 megohms or greater.

The slip ring input and output connectors on the rotary joint shall be MS connectors identical to those currently employed on ASR-4/5, ASR-7, and ASR-8 rotary joints. These connectors shall be interconnected through the slip ring terminal blocks and brushes such that signal paths from the pins of the input connector to the pins of the output connector are identical to those currently employed on ASR-8 rotary joints.

3.3.6 Rotary joint mechanical requirements. - The rotary joint shall mount in ASR-4, ASR-5, ASR-7 and ASR-8 radars without modification of either the ASR pedestal or the rotary joint. The rotary joint shall interface properly will all seals currently employed between the rotary joint and the pedestal in ASR-4, ASR-5, ASR-7, and ASR-8 radars. Adapter fixtures may be employed as required. All adapter fixtures required for installing the rotary joint in any of the four ASR radars shall include provisions for properly mounting and driving all azimuth pulse generators and other ancillary equipments currently interfacing with standard ASR-4, ASR-5, ASR-7, or ASR-8 rotary joints. As in the ASR-8, provisions shall be made for setting the azimuth reference pulse of the azimuth pulse generators to any angle of rotary joint rotation. Weatherproof protective covers for all mechanical input/output ports shall be provided and installed by the Contractor.

The positions and types of all connectors and waveguide ports shall be compatible with existing standard ASR-4, ASR-5, ASR-7, and ASR-8 installations in that it shall be possible to install the rotary joint and make all electrical connections satisfactorily without modifying existing cable or waveguide runs beyond the installation of cable/waveguide adapter components. All such cable/waveguide adapter components required for completely installing the rotary joint at any standard ASR-4, ASR-5, ASR-7, or ASR-8 radar shall be supplied with each rotary joint. The number of adapter components shall be held to the lowest possible.

The rotary joint shall be capable of rotating continuously in both the clockwise and the counterclockwise directions at speeds up to 12.5 rpm and shall not depend upon ASR antenna group components to maintain mechanical alignment.

The rotary joint shall be constructed basically of aluminum alloy and shall be chemically treated to protect against corrosion. The finish shall be even and free of burrs, roughness, and undesirable marks and scratches on all interior and exterior surfaces. The exterior paint shall be in accordance with para. 3.3.2.2. Provisions shall be made to protect against electrolytic action taking place due to contact of dissimilar metals within the joint or at connection points within the RF systems. The rotary joint shall be weatherproof and dust tight. All RF energy handling surfaces shall <u>not</u> use finger stock or like material as a mechanical joint that is subject to movement during rotation.

If periodic lubrication of any part of the rotary joint is required, readily accessible provisions shall be provided on the stationary portion of the rotary joint. It must be possible to perform such lubrication with the rotary joint installed and the antenna rotating. Lubrication of the rotary joint shall not be required more often than once every six months of continuous operation. The design of the rotary joint shall ensure that a leaking lubricant seal cannot result in lubricant flowing into the RF portions of the joint when the joint is mounted in its normal operational orientation.

An access port with weather proof cover for slip ring and brush maintenance shall be provided on the stationary portion of the rotary joint. Brushes must be replaceable through this access port. The access port cover shall be permanently and legibly marked on the exterior surface in ½-inch high letters with the following: "SLIP RING ACCESS, CAUTION, 120 VOLTS".

All rotary joint channels shall be capable of being pressurized to 5 PSIG. A single fitting on the stationary portion of the joint shall be provided for connecting the pressure supply. This fitting shall be easily accessible when the rotary joint is installed. The joint shall not lose more than 1.0 PSI in 1 hour when pressurized to 5 PSIG and rotated at 12.5 rpm. Interchannel leakage is permissible. The coaxial cable connectors on the rotary joint shall be pressure tight so that pressure leakage from the rotary joint will not occur if one or more unpressurized coaxial cables are connected. Waveguide windows for maintaining pressure within the rotary joint when unpressurized waveguides are connected are <u>not</u> required.

Periodic maintenance checks and adjustments, and maintenance and replacement of slip ring brushes and the azimuth pulse generator(s) shall be possible with the rotary joint installed in the ASR pedestal.

3.4 Test and maintenance equipment requirements. - The Contractor's detailed maintenance plan (paragraph 4.4.2) shall list all special tools, fixtures, and test equipments required for field maintenance activities and shall provide a similar list for all depot maintenance activities. All special tools, fixtures, and test equipments required for field maintenance of the antenna and filter (rotary joint) and not readily available on the open market from at least one source as a standard stock item without modification shall be supplied with each antenna (rotary joint). Special tools, fixtures, and test equipments required for depot maintenance activities and not readily available on the open market from at least one source as a standard stock item without modification shall be supplied in accordance with the provisions of the contract.

The Contractor shall minimize the number of special equipments required to install, repair, operate, adjust and maintain the antenna, filter, and rotary joint.

3.5. Materials and construction requirements. - Modular construction shall be used to facilitate maintenance and parts replacement. The antennas shall be easy to disassemble as required for maintenance, inspection and repair.

3.5.1 Printed circuit boards. - All RF printed circuit boards (e.g., strip-line network boards) shall be in accordance with MIL-P-19161 or MIL-P-13949 (base material GR or GX).

3.5.2 Drain holes - The antenna shall be equipped with drain holes so located that water and/or condensed moisture cannot collect when the antenna is in its normal operating position at any angle of tilt under the service conditions of para. 3.2.1. All drain holes shall be screened to prevent the entry of insects.

3.5.3 Threads in aluminum and magnesium alloys. - Threading of aluminum alloy into aluminum alloy or magnesium alloy into magnesium alloy shall not be permitted in the construction of the equipment specified herein. Whenever possible, stainless steel inserts will be used in tapped holes in aluminum.

3.5.4 Thread projection and engagement. - Whenever practical, screws and bolts shall extend at least 1-½ threads beyond the nut or equivalent engaging part, and maximum extension shall not exceed 1-½ threads plus 1/8 inch for screws up to 1 inch in length and ¼ inch plus 1-½ threads for screws over 1 inch in length. Thread engagement in tapped parts other than nuts shall be a minimum thread length equal to the diameter of the screw or bolt.

3.5.5 Locking and safety wiring of screw thread assemblies. All screw thread assemblies shall be properly secured and shall be capable of withstanding vibration under operational and non-operational conditions. All internal bolts, screws, and fasteners within the antenna, filter, and rotary joint shall be safety wired or fitted with lock nuts to preclude their loosening or disengagement during operation.

3.5.6 Connectors. - All connectors shall have solder-on center contacts and all center contacts shall be soldered on. All center contacts shall be captured within the connector body if such connectors are available for the series selected by the Contractor. All connector bodies shall be stainless (i.e., corrosion resistant) steel. Unless otherwise specified herein, all connectors shall be series TNC, N, or SMA and shall meet all requirements of MIL-C-39012 associated with connector materials, design and construction, environmental performance, electrical characteristics,and workmanship.

All connectors inside the antenna shall be either packed with a silicone compound meeting the requirements of MIL-S-8660 or shall be externally sealed with a moisture proofing material meeting the requirements of MIL-A-46146 or MIL-I-81550. Connectors shall not be varnished.

The directional, monopulse, and SLS antenna input/output connectors shall be located in a protected position or provided with a protective guard so that:(a) at all angles of antenna tilt, rain will not fall directly on these connectors and water will not accumulate around the connectors, (b) the connectors are easily accessible for connecting and disconnecting cables and filters, and for taping, and (c) the connectors cannot be easily damaged during antenna handling and installation (e.g., by laying the array structure on its back).

3.5.7 Strip line encapsulation. - All strip-line networks shall be sandwiched between two each 3/32-inch thick (or thicker) aluminum plates each of which is the full length and width of the printed circuit board(s). All strip-line network assemblies which are not subsequently potted as part of a larger assembly shall then be potted in a silicone rubber sealant in accordance with MIL-A-46146 or MIL-I-81550. In order to improve sealant adhesion, the strip-line assembly shall be treated with a primer recommended by the sealant manufacturer prior to potting.

3.5.8 Microstrip encapsulation. - All microstrip networks shall be backed with an aluminum plate 1/8-inch thick or thicker which is the full length and width of the printed circuit board. All microstrip assemblies which are not subsequently potted as part of a larger assembly shall then be coated with a moisture-proofing sealant.

3.5.9 Sealing and gasketing. -With the exception of drain holes (para. 3.5.2), the array structure and backfill radiator shall be completely sealed and gasketed against the entry of water.

3.5.10 Electronics enclosures. - All antenna feed networks and associated connectors and cable assemblies shall be housed in aluminum enclosures. The enclosures shall have sufficient strength and rigidity to prevent damage to these equipments under the environmental conditions of para. 3.2.1.

3.5.11 Sliding contacts.- With the exception of the rotary joint slip rings (para. 3.3.5), electrical components with sliding contacts shall not be employed in the construction of the antenna, filter, or rotary joint.

3.5.12 Terminal. - Terminals and terminal lugs shall be in accordance with Requirement 19, MIL-STD-454.

3.5.13 Bearings. - Only rolling contact bearings shall be used. Bearings shall have a minimum life expectancy of 50,000 hours and shall be in accordance with MIL-STD-454, Requirement 6.

3.5.14 Requests for approval (RFA's)- RFA's shall be submitted in accordance with para. 1-3.14.8 of FAA-G-2100/1. Each RFA submitted shall include a comprehensive description of the subject part to include drawings and definition of the materials, construction, and mounting to be employed. The Contractor's experience with identical or similar parts shall be cited to include summaries of recent environmental test results where available. All FAA and military specifications applicable to the part, the materials in the part, the construction of the part and the testing of the part shall be listed and the Contractor shall state which, if any, of these specifications shall be adhered to in fabricating the part. The Contractor shall provide a concise summary of reasons for not adhering to applicable FAA and/or military specifications when such specifications are available.

3.6 Reliability and maintainability requirements. - The useful service life of the antenna, filter, and rotary joint specified herein shall be 20 years of continuous operation. All components that can reasonably fail with normal use under the environmental conditions of this specification shall be replaceable. All exposed RF components such as radiating elements and reflectors which can be damaged by accidents and/or severe storms shall be replaceable in the field without soldering, without dismounting the antenna from the ASR reflector, and without disassembling the antenna. Individual radiating elements shall be replaceable in 15 minutes or less.

3.6.1 Reliability requirements. - The mean time between failures for the antenna and associated filters (as a system) shall be 40,000 hours. The mean time between failures for the rotary joint (not including brush wear) shall be 40,000 hours. Rotary joint brush life shall be 25,000 hours.

3.6.2 Maintainability requirements. - The time required to maintain one antenna, with its associated filters, over the 20-year service life shall be less than 1000 man hours. The time required to maintain one rotary joint over its 20-year service life shall be less than 250 man hours. These maintenance times include all depot and field activities associated with preventative maintenance, corrective maintenance, performance checks, and refurbishment. The maintenance times also include the time required to dismount and mount the equipments in the field insofar as these activities are associated with maintenance.

3.7 Instruction books - Instruction books, manuscript copy, and reproducible artwork shall be furnished in accordance with FAA-D-2494 (all parts). The size of the instruction books (with covers closed and all fold-outs stowed) shall be 8.5 inches by 11 inches.

The maintenance and step-by-step installation instructions in the instruction book shall be sufficient to permit FAA technicians to install and to completely troubleshoot and repair the equipments. All specials tools, fixtures, and test equipments required for installation and maintenance, but not supplied by the Contractor under this specification, shall be listed and described in the instruction books.

The instruction books shall include copies of Level 2 installation and maintenance drawings in accordance with MIL-D-1000. These drawings shall include exploded-view representations of the physical relationships among the various basic parts, subassemblies, assemblies, and units that comprise each equipment.

Two complete instruction books shall be supplied. One instruction book shall fully document the rotary joint and the second instruction book shall fully document the antenna and associated filters. Each instruction book shall be supplied in two volumes. One volume (Volume II) shall contain all depot maintenance procedures to include troubleshooting instructions and supporting data as well as refurbishment instructions. The other volume (Volume I) of each instruction book shall contain the remainder of the information required by FAA-D-2494. The number of copies of each volume of each instruction book shall be in accordance with the contract.

All instruction book materials shall be validated in accordance with FAA-D-2494. The Contractor shall validate the installation instructions for the antenna (with associated filters) and the rotary joint as follows: (a) a comprehensive engineering review of the instructions shall be performed by Contractor personnel, and (b) the Contractor shall simulate the installation of the equipment at the Contractor's plant by physically placing each piece of hardware in a position representing its proper installed position and simulating the performance of every tool operation using the actual tool intended. The FAA will witness or monitor all validation activities.

The Contractor shall supply draft manuscript for review, revised draft manuscript for approval, and copies of draft manuscript for distribution in accordance with the contract. Draft manuscript for review must include the complete text but may not have all the necessary illustrations. The revised draft manuscript for approval and the copies of draft manuscript for distribution must include legible copies of all illustrations along with the complete text.

4. QUALITY ASSURANCE PROVISIONS

4.1 Design qualification tests.- One antenna, one pair of matched antenna filters, and one rotary joint will be subjected to design qualification tests in accordance with para. 1-4.3.2 of FAA-G-2100/1. The electrical ratings of all components shall be verified by analysis. These rating verifications shall demonstrate that the electromagnetic radiation and power handling capacity requirements of this specification have been met.

4.1.1 Antenna electrical tests.- The following electrical tests shall be performed.

4.1.1.1 Pattern tests.- Antenna pattern tests shall consist of the following:

Test	Reference paragraph
Sum elevation pattern	3.3.1.1.1
Difference elevation patterns	3.3.1.1.2
SLS elevation patterns and phase	3.3.1.1.3
Sum azimuth patterns	3.3.1.2.1
Difference azimuth patterns	3.3.1.2.2
Error azimuth patterns and post-hybrid phase	3.3.1.2.3
SLS azimuth patterns	3.3.1.2.4
Gain	3.3.1.4
Pulse distortion	3.3.1.9
Squint and skew	3.3.1.10
Cross polarization	3.3.1.3

Over each frequency band (1030± 3.5 MHz or 1090± 5 MHz) at which pattern performance is specified, patterns will be recorded at three frequencies corresponding to the two extremes and the midpoint of the frequency band. The sum elevation pattern is therefore to be recorded at six frequencies (1026.5, 1030, 1033.5, 1085, 1090, and 1095 MHz). All pattern cuts shall be over the full range of angles for which performance is specified herein. Azimuth patterns shall generally be recorded in 5-degree steps of elevation from the lowest elevation angle at which pattern performance is specified to the highest; an azimuth cut at zero degrees elevation shall be included in every case. All azimuth patterns shall include both normal and cross polarization measurements. The SLS elevation patterns shall be measured at five azimuth angles equally spaced over 360 degrees and shall be measured over 360 deg. along the vertical plane through the center of the aperture and the local peak of the SLS pattern at zero degrees elevation as well as along the principal elevation plane.

In addition to the patterns specified above, the following SLS patterns shall be recorded at 1030 and 1090 MHz and delivered to the Government. For each combination of front-to-back amplitude ratio (4 each) and phase shift (7 each), the Contractor shall measure SLS elevation plane patterns over 360 deg. along the vertical plane through the center of the aperture and the local peak of the SLS pattern at zero deg. elevation as well as along the principal elevation plane. For each amplitude and phase combination, the Contractor shall also measure 360 azimuth patterns at -2 deg. elev. and in 5 degree steps from 0 to 75 deg. elevation. Each SLS pattern here described for measurement shall be recorded for two conditions as follows: (a) with only the SLS port of the antenna driven (or recorded) and (b) with the SLS and sum ports driven (or recorded) simultaneously such that the resulting pattern represents the power density in free space with the SLS and sum ports simultaneously excited in phase at equal input power levels.

The 1090 MHz, the Contractor shall measure and record the post-hybrid phase over 360 degrees in azimuth in 5-degree steps from 0 deg to + 70 deg. elevation.

For all pattern tests performed under this paragraph, the antenna shall be attached to a Contractor-fabricated structure that represents the entire top surface of the ASR-8 reflector to include the mounting plates of Figure 1. The purpose in including this structure with the antenna during the pattern tests is to insure that the performance requirements of this specification will be met when the antenna is mounted on ASR reflectors.

4.1.1.2 Other electrical tests.- The VSWR at the sum and SLS connectors shall be measured at 1026.5, 1030, 1033.5, 1085, 1090, and 1095 MHz and the VSWR at the difference connector shall be measured at 1085, 1090, and 1095 MHz (para. 3.3.1. 5).

The power handling capability at each antenna connector shall be verified by recording (photographing) forward and reflected pulse waveforms at 200 watts peak and 15,000 watts peak at 1.0 percent duty cycle. Pulse rise times shall be less than 70 nanoseconds. VSWR measurements at the frequencies listed above shall be measured and recorded at 15,000 watts peak input power.

4.1.2 Electrical element testing.- The impact strength of radiating and other electrical elements that extend from the antenna structure will be verified against the hail requirements of para. 3.2.1. One each element of each such type employed on the antenna shall be subjected to 100 impacts each simulating a direct hit by a 1 inch hail stone at 60 feet per second. The simulated impacts shall represent a hail stone falling vertically and at 20° from the vertical onto the element. At the conclusion of impact testing, the VSWR of each radiating element tested shall be measured and shall be less than 1.5:1 at the nominal impedance of the element. Each element shall be carefully inspected following testing and there shall be no evidence of mechanical failure or deterioration in protective coverings beyond the loss of surface finish.

4.1.3 Qualification of mechanical design.- The size and weight requirements of para. 3.3.2.1 shall be validated by direct measurement on a production antenna. Analysis shall be employed to validate the projected area requirement (para. 3.3.2.1).

Comprehensive structural analyses of the array structure as mounted on ASR-4/5, ASR-7, and ASR-8 radars shall be employed to verify that the following structural requirements and mechanical restrictions have been met.

Requirement	Reference paragraph
Array safety factor	3.3.2.4
Array deflections	3.3.2.4
ASR safety factor	3.3.2.5
ASR deflections	3.3.2.5
ASR bearing stress	3.3.2.5
Pedestal drive requirement	3.3.2.5

These analyses shall include detailed load computations for the structural elements of the array antenna and the ASR reflector. The load computations shall be verified by wind tunnel test data for a 1/10-scale model (or larger model) of the ASR-8 antenna group with the array antenna mounted on top. Wind tunnel data with a model of the standard FAA Hogtrough mounted on the ASR-8 shall be included in the validation of the pedestal drive requirements (para. 3.3.2.5). Wind tunnel load data shall be collected with the model both stationary and rotating at a speed representing 12.5 rpm in the full-scale system. Wind tunnel data for both the maximum operating and survival conditions of para. 3.2.1 shall be measured and recorded.

The deflection performance of the array antenna will be validated against the requirements of para. 3.3.2.4 by means of a static load test of a production array structure with its associated support structure. This test shall apply loads representative of maximum array deflections under the most severe operating conditions as established by the Contractor's analysis and verified by wind tunnel data. This static load test shall demonstrate that the array returns to its original contour (to within the Contractor's flatness tolerances) when the load is removed. In addition to the structural analysis and testing required above, the Contractor shall provide comprehensive analyses of the static and dynamic mechanical loads on and deflections of any exposed electrical components such as reflecting elements or screens and radiating elements. These analyses shall demonstrate that these components will survive the environmental conditions of para. 3.2.1 without fracture or permanent deformation.

All analyses and test data required to qualify the mechanical design of the antenna shall be reported in a single comprehensive test report.

4.1.4 Array error analysis and associated testing.- The Contractor shall establish nominal values and allowable variations for the excitation amplitude and phase of each radiating element of the antenna with each of the three antenna inputs driven. A comprehensive statistical analysis of the allowable variations will be performed to demonstrate that at any single point in space the probability of any one antenna parameter not meeting all specifications is less than 0.02. This statistical analysis shall include the effects of radiating element VSWR (or impedence) and the dimensional tolerances and deflections of the antenna under the most severe operating conditions of para. 3.2.1. If array deflections must be less than those specified in para. 3.3.2.4 in order to provide the certainty of electrical performance required above, then the testing of para. 4.1.4 shall demonstrate that these more exacting deflection limits have been adhered to in the Contractor's structural design. The testing of para. 4.1.4 shall demonstrate that the dimensional tolerances of the antenna contour are within the limits assumed by the statistical analysis.

No test procedure is required for the array error analysis. The Contractor shall prepare and submit for approval an interim report and a final report of this analysis. The final report must be approved before the Government will approve the test procedure for para. 4.1.4.1 below.

4.1.4.1 Environmental test of antenna electronics.- The Contractor shall environmentally test one fully assembled antenna less enclosure covers. The enclosure covers are to be removed in order to expose the antenna feed networks to the temperature and humidity conditions of the test chamber. Radiating elements may be removed in order to facilitate the measurement of element excitation voltages as required below.

The antenna shall be placed in a chamber meeting the requirements of para. 1-4.12, FAA-G-2100/1, and subjected to the environmental scenario tabulated therein except that Step 8 shall be deleted and all required measurements shall be taken and recorded after the temperature of the antenna returns to nominal following Step 7. The temperature extremes shall be -50 deg. C and +70 deg. C and the high humidity level shall be 100% (-5%, +0%).

At each point in the environmental scenario at which test measurements are to made, the phase and amplitude of the excitation at 100 radiating elements selected by the FAA shall be measured and recorded. Each measurements shall lie within the range about its nominal value prescribed by the Contractor's allowable variation for that output. The excitation levels at radiating elements will be measured as specified above with the sum, with the difference, and with the SLS ports separately driven at power levels below 10 dbm.

At the extremes of temperature, the allowable variations in excitation level shall not exceed $\pm$2.5 dB relative to the nominal and the allowable variation in excitation phase shall not exceed $\pm$20 degrees relative to the nominal. At room temperature, the allowable variations in excitation amplitude and phase shall be less than $\pm$1.5 dB and $\pm$15 degrees respectively. The nominal excitation levels and phases can be made a function of temperature only to the extent that all nominal levels and/or nominal phases change by the same amount for the antenna input in question and only to the extent that the gain and relative amplitude and phase requirements of para. 3.3.1 are met.

4.1.4.2 Environmental test of antenna radiating elements. - The Contractor shall environmentally test 25 radiating elements of each type employed using a chamber and scenario satisfying the requirements of para. 4.1.5.1 above. At each point in the environmental scenario at which test measurements are to be made, the VSWR of each element shall be measured and recorded. Each measurement shall lie within the range assumed in validating antenna performance with the statistical analysis of para. 4.1.5. At the extremes of temperature, all element VSWR's shall be less than 2.0:1 referenced to the nominal element impedance and, at room temperature, all element VSWR's shall be less than 1.5:1.

4.2 Type tests. - The antenna, filters and rotary joint will be type tested as specified below in accordance with para. 1-4.3.3 of FAA-G-2100/1.

4.2.1 Antenna tests. - The following electrical tests shall be performed on each antenna type tested:

Test	Reference paragragh
Sum elevation pattern	3.3.1.1.1
Difference elevation pattern	3.3.1.1.2
SLS elevation patterns and phase	3.3.1.1.3
Sum azimuth patterns	3.3.1.2.1
Difference azimuth pattern	3.3.1.2.2
Error azimuth pattern and post-hybrid phase	3.3.1.2.3
SLS azimuth pattern	3.3.1.2.4
Gain	3.3.1.4
Pulse distortion	3.3.1.9
Squint and skew	3.3.1.10
Cross polarization	3.3.1.3

All sum and SLS patterns shall be measured at 1030 and 1090 MHz. Difference patterns shall be measured at 1090 MHz only. All pattern cuts shall be over the full range of angles for which performance is specified herein. Azimuth patterns shall generally be recorded in 5-degree steps of elevation from the lowest elevation angle at which pattern performance is specified to the highest; an azimuth out at zero deg. elevation shall be included in every case. All azimuth patterns shall include both normal and cross polarization measurements. The SLS elevation patterns shall be measured at five azimuth angles equally spaced over 360 degress and shall be measured over 360 deg. along the vertical plane through the center of the aperture and the local peak of the SLS pattern at zero degress elevation as well as along the principal elevation plane. For all the pattern tests performed under this paragraph, the Contractor-fabricated structure attached to the antenna for the tests of para. 4.1.1.1 shall not be mounted on the antenna.

In addition to the pattern tests specified above, the VSWR and power capacity measurements of para. 4.1.1.2 shall be included in the type tests.

4.2.2 Filters tests.- Filters shall be type tested in matched pairs. Each matched pair of antenna filters tested shall be subjected to the following electrical tests under the environmental conditions specified below:

Test	Reference paragraph
Pass-band attenuation	3.3.3
Stop-band attenuation	3.3.3
VSWR	3.3.3
Power capacity	3.3.3
Phase shift (tracking)	3.3.3
Insertion loss (tracking)	3.3.3
Pulse shape	3.3.3
Pulse shape (tracking)	3.3.3

The power capacity measurements shall be made in accordance with para. 4.1.1.2 to include the high-power VSWR measurements. The environmental conditions for the filter type tests shall be in accordance with para. 1-4.12, FAA-G-2100/1, modified as follows:

(a) In Step 3, the temperature shall be held at the minimum for a time interval sufficient to ensure that the entire filter has cooled to at least -45°C prior to making measurements.

(b) Delete Step 8. One complete set of test measurements shall be made at the conclusion of Step 7.

The temperature limits for type testing are -50°C and +70°C. The high humidity value is 100% (-5%, +0%).

4.2.3 Rotary joint type tests.- The following electrical tests shall be performed on each rotary joint tested.

Test	Reference paragraph
Isolation	3.3.5
Peak power	3.3.5
Duty cycle	3.3.5
VSWR	3.3.5
Insertion loss	3.3.5
Phase shift change	3.3.5
Pulse shape (Channels 4, 5, & 6)	3.3.5
Phase and amplitude tracking (Ch. 4 & 5 and 4 & 6)	3.3.5
Pulse shape tracking (Ch. 4 & 6)	3.3.5
Frequency	3.3.5

The environmental conditions for the rotary joint type tests shall be in accordance with para. 1-4.12, FAA-G-2100/1, modified as follows:

(a) In Step 3, the temperature shall be held at the minimum for a time interval sufficient to ensure that the entire rotary joint has cooled to at least -45 deg.C prior to making measurements.

(b) Delete Step 8. One complete set of test measurements shall be made at the conclusion of Step 7.

The temperature limits for type testing are -50 deg. C and +70 deg. C. The high humidity value is 100% (-5%,+0%).

The type test shall be in three segments. Segment I shall make all measurements tabulated above at room temperature at three angles of joint rotation evenly distributed over 360 degrees. Segment II shall make all measurements tabulated above over the environmental scenario of para. 1-4.12, FAA-G-2100/1, (as modified above) with the joint either rotating or stationary in the chamber. Segment III shall make low power phase and amplitude tracking and pulse shape tracking measurements with the rotary joint continuously rotating at a speed gretater than 10 rpm and subjected to the environmental scenario. If the Contractor so elects, Segments II and III may be combined into a single segment.

4.3 Production tests.- The following production tests shall be conducted in accordance with para. 1-4.3.4, FAA-G-2100/1.

4.3.1 Antenna tests.- The following electrical tests shall be performed on each antenna.

Test	Reference paragraph
Sum elevation pattern	3.3.1.1.1
Difference elevation pattern	3.3.1.1.2
SLS elevation pattern and phase	3.3.1.1.3
Sum azimuth pattern	3.3.1.2.1
Difference azimuth pattern	3.3.1.2.2
Error azimuth pattern and post-hybrid phase	3.3.1.2.3
SLS azimuth pattern	3.3.1.2.4
Gain	3.3.1.4

All sum and SLS patterns shall be measured at 1030 and 1090 MHz. Difference patterns shall be measured at 1090 MHz only.

4.3.2 Filter tests.- Each matched pair of antenna filters shall be subjected to the following electrical tests.

Test	Reference paragraph
VSWR	3.3.3
Phase shift (tracking)	3.3.3
Insertion loss (tracking)	3.3.3
Pass-band attenuation	3.3.3
Stop-band attenuation	3.3.3

4.3.3 Rotary joint tests.- Each rotary joint shall be subjected to the following electrical tests following 168 hours of continuous rotation at 12.5 rpm.

Test	Reference paragraph
VSWR	3.3.5
Insertion loss	3.3.5
Phase and amplitude tracking (Ch. 4 & 5 and 4 & 6)	3.3.5
Pressure leakage	3.3.6

During the 168 hour run-in of the rotary joints all azimuth pulse generator (APG) mechanical drives shall be loaded to supply 30 inch-ounces of torque to external sinks. In addition, all slip ring circuits shall carry 5 amps at 60 Hz throughout the 168 hour test. At the end of the run-in it shall be established that the slip rings and brushes are functioning normally and that all APG drives meet the following requirements when an azimuth pulse generator is mounted in its normal operational position and the rotary joint is rotated at 12.5 rpm ± 10%.

		ACP	ARP
(a)	Pulse-to-pulse jitter (measured at 50% amplitude points)	± 15% of nominal spacing	± 25% of nominal spacing
(b)	Pulse count	4096 per 360° of rotation	1 per 360° of rotation

4.4 Maintainability program.- The Contractor shall perform a comprehensive maintainability program in accordance with MIL-STDs 470 and 471, and MIL-HDBK-472, for both the antenna (with filters) and the rotary joint.

4.4.1 Maintainability program plan.- The Contractor shall prepare, and submit for approval, a maintainability program plan in accordance with MIL-STD-470. The description of the work to be performed on each program task shall include a concise description of the objective of each task. It shall be clear from the program task descriptions that the relevant objectives are met. The program plan shall include a milestone chart that clearly shows the time interval over which each task will be performed. The development of the maintainability data base and related models required to support analyses and predictions shall be one specific identifiable task in the program plan.

4.4.2 Detailed maintenance concept and detailed maintenance plan.- The Contractor shall formulate a detailed maintenance concept and a detailed maintenance plan in accordance with MIL-STD-470. The detailed maintenance plan shall include a summary description of each maintenance task to be performed in the field, at the FAA depot, or at any other facility. Task descriptions shall encompass all maintenance activities to include performance checks, fault diagnosis, disassembly, part interchange, part refurbishment, reassembly, alignment, and checkout. The frequency with which each task is to be performed shall be stated along with a description of the location (field, FAA depot, etc.) at which the task is carried out. Support equipment, special tools and test equipments, skill levels, and number of people required for each task shall be described. The maintenance concept and detailed maintenance plan for the antenna, filters, and rotary joint shall be consistent with the useful service life requirement of para. 3.6.

The format of the detailed maintenance plan shall include both an overview of the maintenance activities required and self-contained descriptions of each maintenance task to include the information described above. All of the maintenance tasks, procedures, and related data described in the instruction books (paragraph 3.7) shall be obtained from this maintenance plan as developed by the contractor.

The detailed maintenance plan shall include a concise list of all special tools, fixtures, and test equipments required for field maintenance activities and a similar list for depot maintenance activities.

The Contractor's maintenance concept and detailed maintenance plan shall be justified by supporting analyses. These analyses shall demonstrate that the maintenance procedures, tasks, and data prescribed in the instruction books are sufficient to assure that operational (installed) equipments [illegible] Preventative maintenance [illegible] scheduled [illegible] (e.g., bearing) [illegible] performance, and can [illegible] frequency of such failures shall be [illegible] to the maximum extent possible. [illegible] checks will be [illegible] not any of the [illegible] shall demonstrate that the [illegible] sufficient to [illegible] prescribed for [illegible] failure rates.

The maintainability [illegible] shall adhere to the following [illegible]

(a) [illegible] be disassembled [illegible]

(b) [illegible] shall minimize, to the [illegible] personnel must [illegible]

(c) The periodic field [illegible] shall include the measurement of the [illegible] field radiated by each individual radiating element of the antenna using a suitable [illegible] probe placed over the element.

(d) Requirements for special test equipment and tools shall be [illegible] in the current FAA inventory [illegible] possible.

4.4.3 <u>Maintainability [illegible]</u> [illegible] shall use Procedure IV of MIL-HDBK-[illegible] the maintainability requirements [illegible] over the service life of the equipment. [illegible] IV [illegible] by the Contractor, as required, [illegible] environment, and maintenance [illegible] rotary joints. In addition, [illegible] data generated by the Contractor shall include, [illegible] parameters specified in paragraph [illegible]

4.4.4 <u>Maintainability [illegible]</u> [illegible] Maintainability demonstration shall be limited [illegible] times shown in the maintainability [illegible] in maintainability predictions and shall be [illegible] (Phase II). The Government shall [illegible] simulation shall not be employed. [illegible] times shall be comprehensive [illegible] inherent in working on the equipment [illegible], MIL-STD-471). The maintainability [illegible] Contractor personnel (to include the test [illegible] shall be witnessed by Government personnel.

Whenever a maintenance task time from the maintainability demonstration exceeds the predicted time by more than 20%, the maintenance task time from the maintainability demonstration shall be used as the time required for the task and the maintainability predication of para. 4.4.3 shall be used to show that all maintainability requirements are met when the new task time is used in the prediction.

The Contractor shall submit a test plan in accordance with paragraph 4.2.6 of MIL-STD-471 based upon the maintenance tasks selected by the Government for demonstation. These tasks shall be selected from a draft of the Contractor's detailed maintenance plan and preliminary maintainbility data base information. The Contractor's maintenance program plan shall provide for the timely submittal of the necessary draft maintenance plan, preliminary maintainability data base, and test plan. The test plan shall be submitted 30 days prior to the scheduled date for maintainability demonstration testing.

4.4.5 Maintainability data base.- All reliability and maintainability data employed in maintainability analyses, maintenance concept/plan justification, and maintainability prediction shall be collected into a comprehensive maintainability data base. A separate section of the maintainability status reports shall be devoted to describing the maintainability data base as it evolves. This description of the data base shall include:

(a) The name of each relevant reliability and maintainability variable.

(b) The symbol used to represent each variable in maintainability calculations.

(c) The definition of each variable to include units.

(d) The numerical value or range of values assigned to each variable.

(e) The justification for each numerical value used.

Numerical values assigned shall be justified based upon verification simulations, documented experience with the same or related equipments and materials, and/or engineering judgment. Reliability data shall be derived from the Contractor's reliability data base (paragraph 4.5.6).

4.4.6 Maintainability status reports.- All maintainability program activities described in paragraph 4.4 of this specification shall be reported in comprehensive maintainability status reports. These reports shall be prepared in accordance with MIL-STD-470 and shall be submitted according to the Contractor's maintainability program plan. Up-to-date maintainability status reports shall be submitted at least every two months from date of contract through completion of all maintainability program activities. The first maintainability status report shall include the maintainability program plan. The maintainability program plan shall show the submission dates and corresponding Government reviews for maintainability status reports on the milestone chart of program activities. A narrative discussion keyed to the milestone chart shall outline the contents of each report. All maintainability status reports shall be subjected to Government review and approval.

4.5 Reliability program.- The Contractor shall perform a comprehensive reliability program for the antenna (with filters) and rotary joints.

4.5.1 Reliability program plan.- The Contractor shall prepare, and submit for Government approval, a reliability program plan in accordance with MIL-STD-785 and this specification. This program plan shall include a detailed milestone chart showing the time interval over which each major reliability program activity will be performed.

4.5.2 Reliability apportionment.- In accordance with MIL-STD-785, the Contractor shall employ standard analytical reliability engineering techniques to apportion (or allocate) the MTBF requirements for the antenna (with filters) and the rotary joint to MTBF requirements for the major assemblies and components that comprise the equipments. Antenna components and assemblies to which MTBF requirements are apportioned shall include, as appropriate, radiating elements, power dividers and feed networks, cables and connectors, and protective coverings (radomes). The reliability prediction activity of paragraph 4.5.3 shall establish that the reliability requirement apportioned to each component and assembly is satisfied when the materials and construction techniques of the Contractor's design are employed.

4.5.3 Reliability prediction.- The Contractor shall perform a reliability prediction in accordance with the Design Prediction Procedure of MIL-STD-756. This prediction shall utilize the hardware breakdowns developed under paragraph 4.5.2 above. The prediction shall demonstrate that all of the reliability requirements apportioned to equipment assemblies and components will be achieved using the materials and construction techniques of the Contractor's design. In addition, the reliability prediction shall demonstrate that the antenna (with filters) and the rotary joint will meet the reliability requirements of paragraph 3.6. The use of MIL-HDBK-217 is not mandatory (para. 5.9.1, MIL-STD-756).

4.5.4 Reliability demonstration.- The Contractor shall perform reliability demonstrations in accordance with MIL-STD-781. These demonstrations shall test one antenna (with matched filters) and one rotary joint to demonstrate that the reliability requirements of paragraph 3.6 have been met. Reliability production acceptance (sampling) tests are not required.

The test level for exercising the equipments for all demonstrations shall be test level E of MIL-STD-781 modified as follows:

(a) Temperature limits: - 50°C to + 70°C

(b) Vibration limit: 1.0G ± 10%

(c) The antenna, filters, and rotary joint need not be operated during reliability testing.

The test plan shall meet the requirements listed below and need not be one of the test plans (e.g. Test Plan XXV) listed in MIL-STD-781.

(a) One antenna (with filters) and one rotary joint shall each be exercised for a total of 600 hours.

(b) The antenna will be fully assembled or else exercised in two sections. The filters will be mounted in their normal operational configuration. The support structure need not be exercised.

(c) The rotary joint will be exercised as a fully assembled unit.

(d) At the conclusion of the antenna exercise period, the tests of para. 4.2.1 and 4.2.2 shall be performed on the antenna and the filters respectively. Any test measurement that does not meet all requirements of this specification shall constitute a failure of the antenna reliability demonstration.

(e) At the conclusion of the rotary joint exercise period, the tests of para. 4.2.3 shall be performed. Any test measurement that does not meet all requirements of this specification shall constitute a failure of the rotary joint reliability demonstration.

(f) No preventative maintenance may be performed at any time during the reliability demonstration. However, if the Contractor so elects, the chamber may be opened and test measurements may be performed at intervals not more frequent than once per week. The time that the chamber is open will not count toward the required 600-hour test duration. The FAA will witness all such test measurements and three days notice will be provided by the Contractor.

A detailed test procedure for the reliability demonstration tests shall be prepared in accordance with MIL-STD-781 and submitted to the Government for approval 60 days prior to testing. Reliability records will be kept in accordance with paragraph 5.10 of MIL-STD-781 and FAA Handbook 6040.10. Reliability test reports shall be submitted in accordance with paragraph 5.11 of MIL-STD-781 for all reliability demonstrations conducted.

4.5.5 Reliability data base.- All reliability data employed in the predictions required by paragraph 4.5.3 shall be collected into a comprehensive reliability data base. A separate section of the reliability status reports shall be devoted to describing the reliability data base as it evolves. This description of the data base shall include:

(a) The name of each reliability variable

(b) The symbol used to represent each variable in reliability predictions

(c) The definitions of each variable to include units

(d) The numerical value or range of values assigned to each variable.

(e) The justification for each numerical value used.

The justifications for the numerical values assigned shall be comprehensive and shall be based upon standard sources (e.g. MIL-HDBK-217) to the extent possible. Where standard data sources do not exist, numerical values shall be justified based upon documented experience with the same or related equipments and materials and/or engineering judgment. Exceptions to published DOD sources of applicable reliability data shall not generally be allowed.

4.5.6 Reliability status reports.- Test data reports shall be submitted as described in para. 4.5.4. All other reliability program activities described in paragraph 4.5 of this specification shall be reported in comprehensive reliability status reports. These reports shall be prepared in accordance with MIL-STD-785 and shall be submitted according to the Contractor's reliability program plan. Up-to-date reliability status reports shall be submitted at least monthly from date of contract through completion of all program activities. The first reliability status report shall include the reliability program plan. The reliability program plan shall show submission dates and corresponding Government reviews for reliability status reports on the milestone chart of program activities. Reliability status reports will be subject to Government review and approval.

4.6 Failure recording and reporting.- Failures during all test programs specified herein shall be recorded and reported in accordance with FAA Handbook 6040.10 "Equipment Failure Handbook". The failure reporting form specified in the handbook shall be modified to include the reporting of the following additional data:

(a) Time of day failure occurred.

(b) Downtime reported to the nearest minute.

(c) Time of restoration of equipment to full service.

Copies of all failure reports shall be made a part of the appropriate test reports.

4.7 Test range capability.- The Contractor's test range shall met the following requirements.

(a) The length of the test range shall be $2D^2/\lambda$ or greater. (D is the maximum dimension of the antenna and λ is the wavelength at which the antenna is being tested.)

(b) The source antenna dimensions and alignment shall be such that the maximum amplitude taper will not exceed 0.25 dB over the test aperture and the taper shall be centered on the test aperture.

(c) Under all test conditions, the ratio of co-polarized direct-to-reflected path signal levels that will be detected by the antenna shall be 35 dB or greater. This value shall be met when the source antenna is radiating either vertically or horizontally polarized energy.

(d) Under all test conditions, the ratio of co-polarized to cross-polarized signal levels over the aperture of the antenna shall be 35 dB or greater. This value shall be met when the source antenna is radiating horizontally or vertically polarized energy.

To demonstrate that requirements (b) through (d) above have been met, the Contractor shall record the probe data described in para. A2.4 of Appendix 2. These data shall meet all requirements listed in para. A2.4.

The Contractor shall prepare, and submit for Government approval, a test range validation report which verifies that the above range requirements have been met for all ranges that will be employed for the antenna tests of para. 4. This validation of antenna test range capability shall be submitted to the Government 90 days prior to the start of related testing activities.

The Contractor shall submit, within 90 days after award of contract, a plan and schedule for providing the required range facilities.

5. PREPARATION FOR DELIVERY

The antennas (with filters) and rotary joints shall be packed, packaged, and marked in accordance with the contract.

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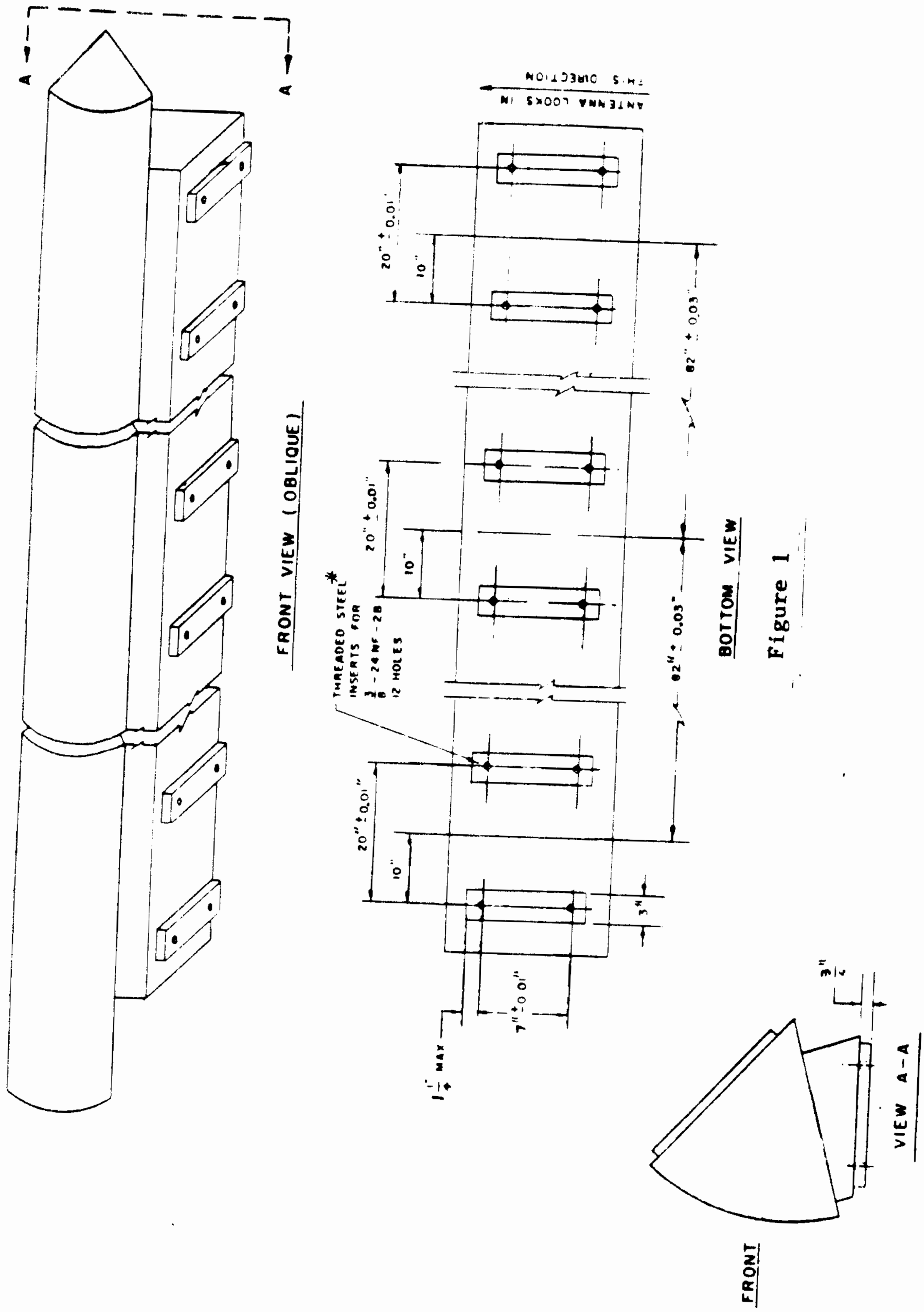

Figure 1

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ANTENNA TEST RANGE

A2.1 Introduction

This appendix is referenced in para. 4.7 of the main specification and establishes design guidelines and probe data requirements for the test range(s) that will be employed in verifying antenna performance.

The purpose of antenna testing is to determine how the antenna will perform under actual operating circumstances. For this reason, it is important to assess the characteristics of the antenna itself, and not of the antenna in one particular environment. Ideally, the test antenna would be placed in free space with a source antenna at a near infinite separation. This would permit measurement of the characteristics of the antenna in the absence of external interference and in an incident field uniform in both phase and amplitude. However, this is not possible and restrictions must be established on the actual test environment.

A test environment in which the phase taper across the test antenna is minimal must be provided. If this taper is too severe, the antenna does not integrate the energy over its surface in the same manner as it does at extremely large separations and the resulting patterns are distorted. Acommonly employed criterion is to restrict this phase taper to a maximum of $\pi/8$ radians or 22.5 electrical degrees. Secondly, the amplitude taper across the antenna must be maintained at a minimal amount. The primary effect of moderate amplitude taper in the incident field is to produce errors in the relative levels of the minor lobes of the radiation pattern and to indicate a gain slightly less than the actual value.[1] For most antennas to be tested, an incident field which is constant

[1] Chastain, J. B., et al, Investigations of Precision Antenna Pattern Recording and Display Techniques., Section 2.1D4/5-912, April 1963

in amplitude to within 0.25 decibel over the aperture area should ensure negligible error. Finally, all extraneous energy resulting from reflections from surrounding objects, diffraction effects, etc. must be kept to, or below, a predetermined level to meet the allowable error requirements for the tests to be made. In addition to the above restrictions which are electromagnetic in nature, test fixtures must have the mechanical stability and positioning accuracy to perform the required tests. These mechanical requirements are very important, but this discussion will be restricted to electromagnetic characteristics and the above electrical considerations shall be of paramount importance. In the following sections, the elevated range test configuration will be discussed. The design of an elevated range should be directed toward suppressing the unavoidable reflections from the earth's surface by a combination of directive source antennas, large source and receive tower heights, diffraction fences, and judicious positioning of the antenna under test.

A2.2 Source Antenna Illumination Tapers

A2.2.1 Phase Variation of Incident Field

The allowable phase curvature across an antenna under test depends almost entirely on its separation from the source antenna. If the receiving antenna is in the far zone of the transmitting antenna, the phase front of the approaching wave deviates very little from a section of a spherical surface centered on the transmit antenna over the main portion of the main lobe.[2]

This can be seen in Figure A2.1 which is a graph of the calculated phase deviation in degrees over a spherical surface through the main lobe of the beam produced by a circular transmitting aperture.[3] A 30 db Taylor distribution[4] is assumed and four different distances are assumed from the transmitting antenna to the spherical surface: d^2/λ, $2d^2/\lambda$, $4d^2/\lambda$, and infinite where d is the aperture width of the transmitting antenna.

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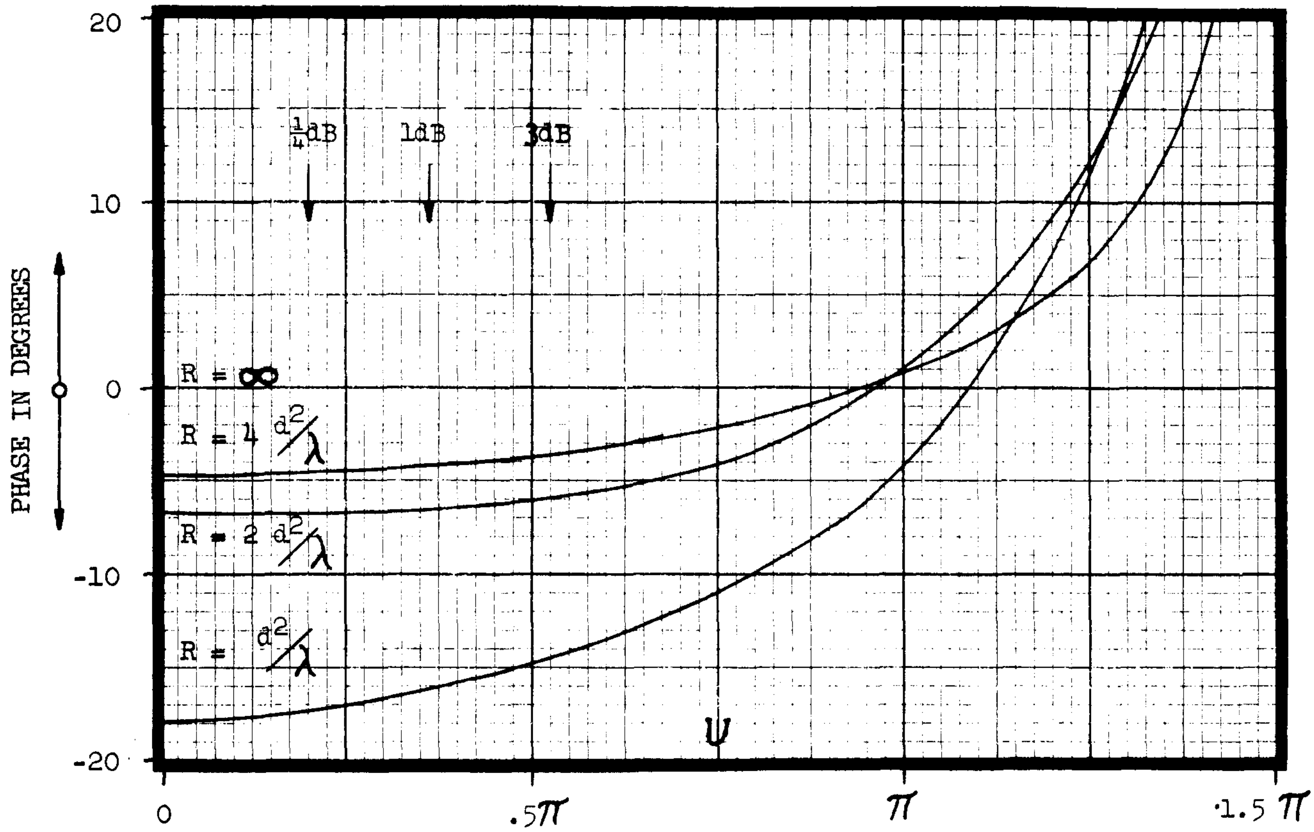
[2] Ibid.

[3] Hollis, J. S., et al, Microwave Antenna Measurements, Scientific-Atlanta, Inc., 1969, p 14-6.

[4] Hansen, R. C., "Tables of Taylor Distributions for Circular Aperture Antennas," IRE Transactions on Antennas and Propagation, Vol. AP-8, pp. 23-26, January 1960.



FigureA2.1 Deviation of transmitted phase front from spheres centered on transmitting antenna. R is radius. A 30 dB Taylor aperture distribution is assumed.

The main lobe extends from approximately $U = -1.6\pi$ to $U = 1.6\pi$, where $U = (\pi/\lambda)\ d \sin \theta$. Even at a range as small as d^2/λ, the phase front is spherical to within 2 degrees between the 1 decibel points of pattern; this condition is typical of reasonably focused symmetrical antennas. When the transmitting antenna is focused at the test range, the phase front will be essentially that for $R = \infty$. When the transmitting antenna is significantly defocused, slightly greater phase variation will be experienced. In any event, the deviation of the phase front from spherical between the 1/4 decibel points of the beam will be small.

From Figures A2.1 and A2.2, it can be seen that the phase variation across the area occupied by a test antenna is almost entirely due to the spherical nature of the wave emanating from the transmitter antenna. This deviation can be calculated from the geometry of Figure A2.2.
D is the maximum aperture dimension of the antenna under test and R is the distance from the test antenna to the center of phase of the source antenna.

From the figure,

$$(R + \Delta)^2 = R^2 + (D/2)^2 \tag{2.1}$$

hence

$$\Delta^2 + 2R\Delta = D^2/4 \tag{2.2}$$

or

$$\Delta = D^2/8R \tag{2.3}$$

for $\Delta \ll 2R$.

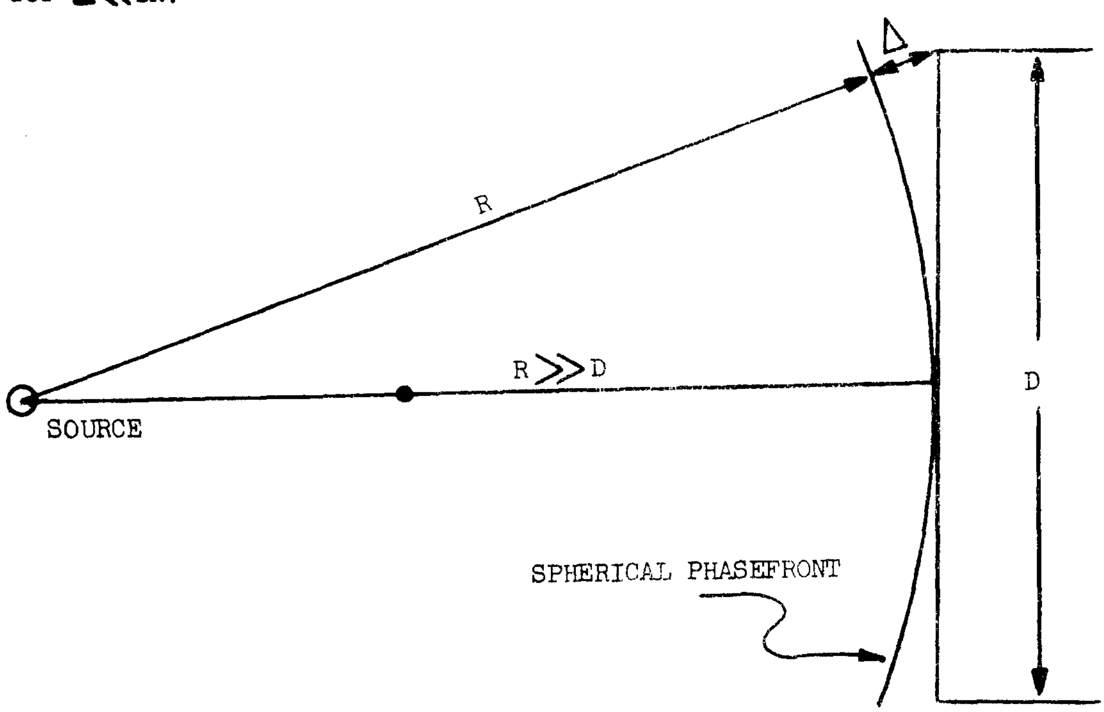


Figure A2.2 Section through incident phasefront at a test separation R>>D.

The resulting phase deviation at the extremes of the test aperture as compared to that at the center is then

$$\phi = \frac{2\pi}{\lambda} (D^2/8R) \text{ radians.} \qquad (2.4)$$

A commonly employed criterion is a phase restriction of 22.5 degrees, ($\phi = \pi/8$), which when substituted into equation (2.4) yields:

$$R \geq 2D^2/\lambda . \qquad (2.5)$$

If antenna measurements are made at a range of $2D^2/\lambda$, there will be a significant departure of the nulls of the radiation pattern and the location and levels of the minor lobes from their infinite-range values. The amount of the deviation depends on the original side-lobe level and structure. D. R. Rhodes[6] calculated that at a range of $2D^2/\lambda$ the first null of the pattern produced by a rectangular aperture with uniform illumination has a level of about -23 decibels instead of $-\infty$ decibels. This deviation is caused only by phase-error effects; the incident-wave amplitude over the test aperture was assumed constant. The infinite range pattern in the above case has a $\frac{\sin x}{x}$ configuration with a first-lobe level of about -13 decibels.

Figure A2.3 is a graph showing the infinite range pattern of a circular aperture with a 30 decibel Taylor distribution and the patterns at separations of $2D^2/\lambda$ and $4D^2/\lambda$ as calculated by a Fourier Integral Computer.[7] If an antenna such as this is adjusted for optimum focus at a range of $2D^2/\lambda$ or $4D^2/\lambda$ for example, the antenna will be lightly defocused for operation at extreme ranges. It is evident that, for extreme accuracy of the infinite-range side-lobe structure, measurements must be made at a range which is appreciably greater than $4D^2/\lambda$.

The above separation criterion is equally valid for the ground reflection mode of operation. In the case of the ground reflection range, R is the separation between the source-image array and the test aperture. 8, 9

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[6]Rhodes, D. R. "On Minimum Range for Radiation Patterns," Proc. I. R. E. Vol. 42, No. 9, pp 1408-1410, September 1954.

[7]Hollis, J. S. et al, op cit.

[8]Hollis, J. S., et al, A Precision Ground-Reflection Antenna Boresight Test Range prepared for presentation at 14th Annual Symposium on USAF Antenna Research and Development, University of Illinois, October, 1964.

[9]Lyon, T. J., et al, Evaluation of the NASA-KSC-MILA RF Boresight Test Facility at X-Band and S-Band, Final Report, Contract No. NAS10-2103, May, 1966.

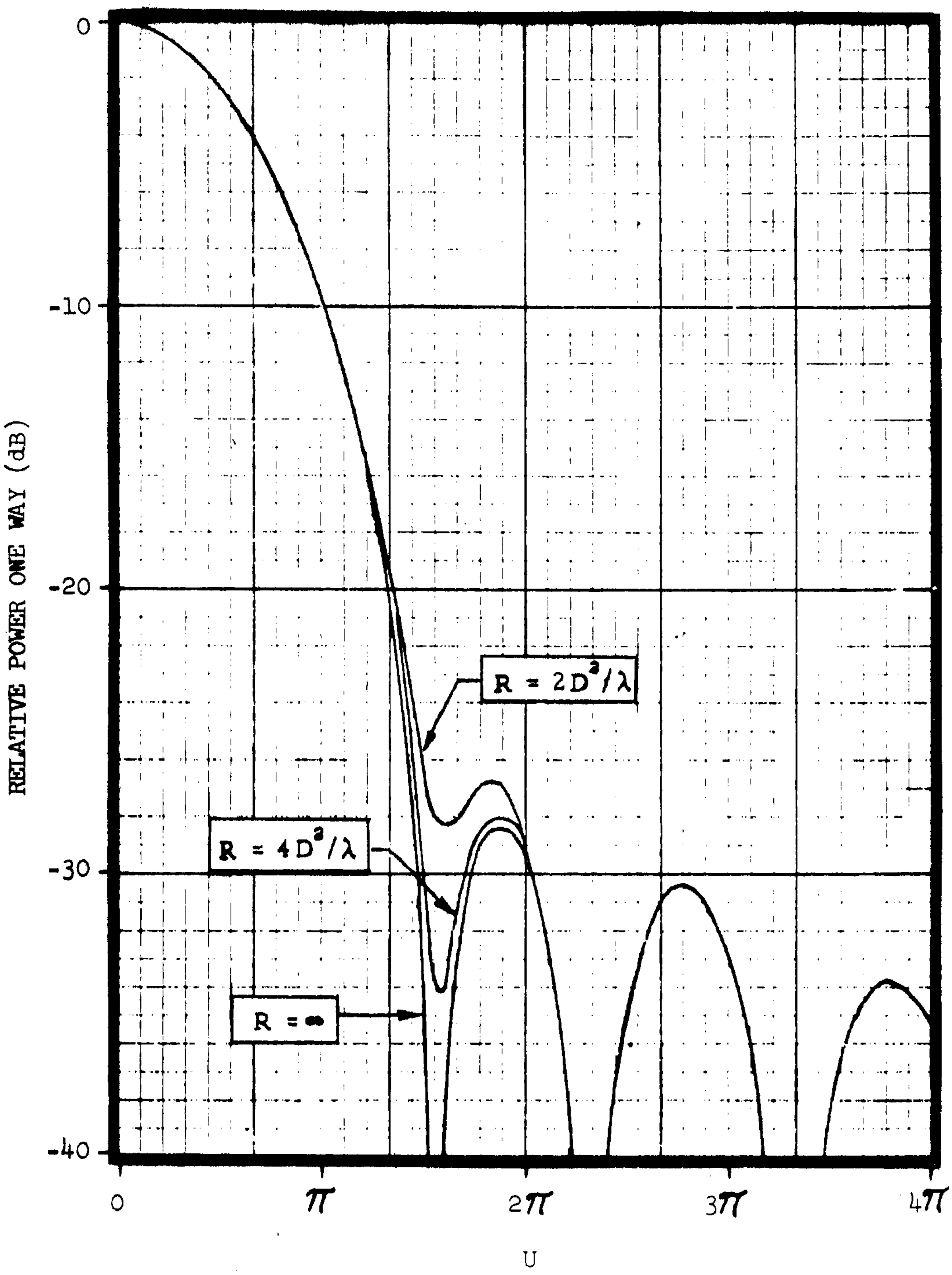

Figure A2.3 Calculated radiation patterns of a paraboloid with quadratic phase errors encountered in measuring at three ranges as indicated.

Actual calculated patterns for these various test separations are shown in Figures A2.4 through A2.7. A 10-decibel cosine aperture illumination function on transmitting was assumed for these patterns. This illumination function is very similar to that of many commonly used microwave antennas. The true pattern for the antenna is shown in Figure A2.4 which represents illumination by a plane wave of uniform amplitude. As the test separation is decreased, as is shown sequentially in Figures A2.5 through A2.7, the nulls fill in and the sidelobes are raised. This is accompanied by a lower measured gain for the antenna. More will be said about this gain reduction in the following section.

A2.2.2 Amplitude Taper Over the Test Aperture

The effect of amplitude taper of the incident field over the test aperture on receiving can be considered from the viewpoint of reciprocity.[10] Variation of the amplitude of the field over the aperture on receiving is analogous, within the accuracy of the aperture field approach, to the modification of the aperture illumination by the primary feed on transmitting. For example, consider the pattern of an antenna whose feed would produce an aperture illumination $f(\theta,r)$ on transmitting, where (θ,r) indicates position in the aperture. If illuminated on receiving by a source antenna which produces over the test aperture an amplitude taper $g(\theta,r)$, the measured pattern would be that of a transmitting antenna illuminated by a feed which produces an illumination of $f(\theta,r)\ g(\theta,r)$ over the aperture. If $g(\theta,r)$ is constant in amplitude and phase over the aperture, the measured pattern will be the same as the infinite-range pattern for the illumination $f(\theta,r)$. The greater $g(\theta,r)$ deviates from constant, the greater will be the deviation of the measured pattern from the infinite-range pattern. The quantitative effect of nearly constant functions $g(\theta,r)$ cannot be determined, however, without assumption of $f(\theta,r)$.

Figure A2.8 is a calculated infinite-range pattern of a circular aperture with a 10-decibel cosine taper distribution as tested with a source antenna which produces a circularly symmetric amplitude taper of 0.5 decibels at the periphery.[11] The taper is assumed to have a $\frac{\sin x}{x}$ form which closely approximates a large portion of the transmitted beam of most narrow-beam antennas. The effects of amplitude taper on the calculated patterns are not nearly as dramatic as the effects of phase taper caused by short range lengths. The calculated patterns show nearly identical close-in sidelobes. The reduction in gain is about 0.15 decibel for the 0.5 decibel taper.

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[10] Chastain, J. B., et al, op cit

[11] Hollis, J. S., et al, op cit

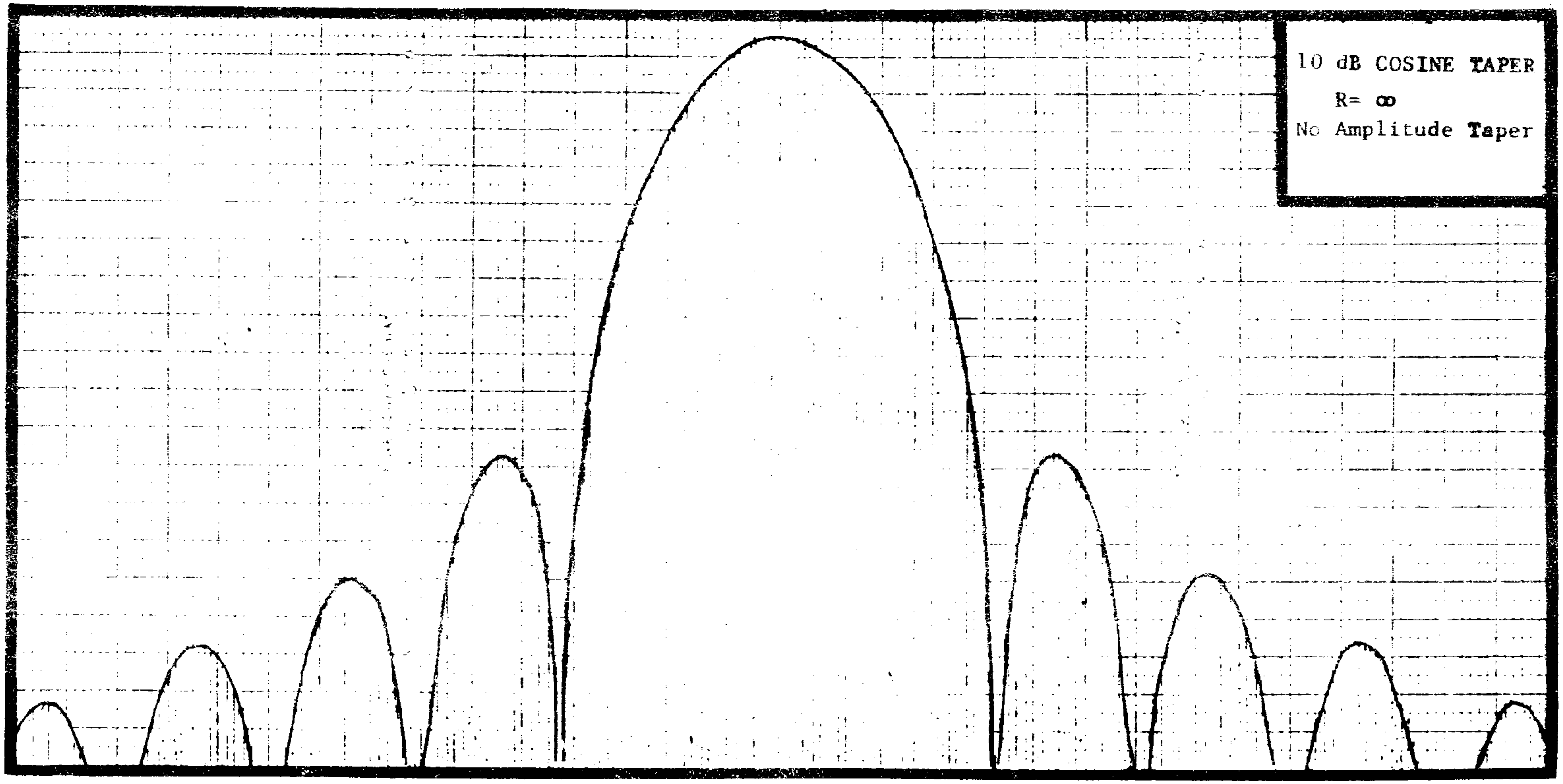

Figure A2.4 Calculated pattern of an antenna with a 10dB Co..ne feed illumination function.

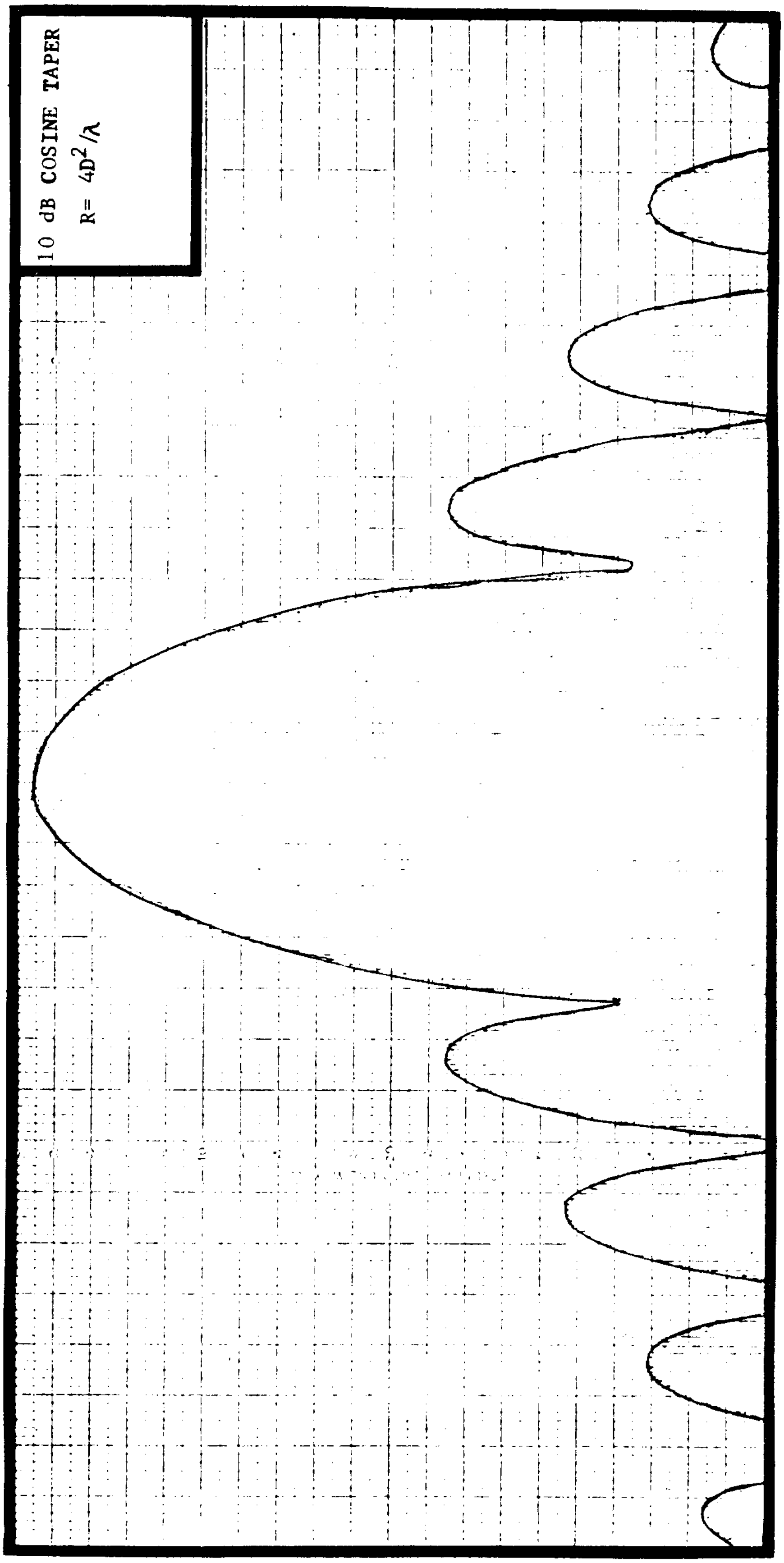

Figure A2.5 Calculated pattern of an antenna with a 10dB Cosine feed illumination function. A phase error is assumed which corresponds to a test separation of $4D^2/\lambda$.

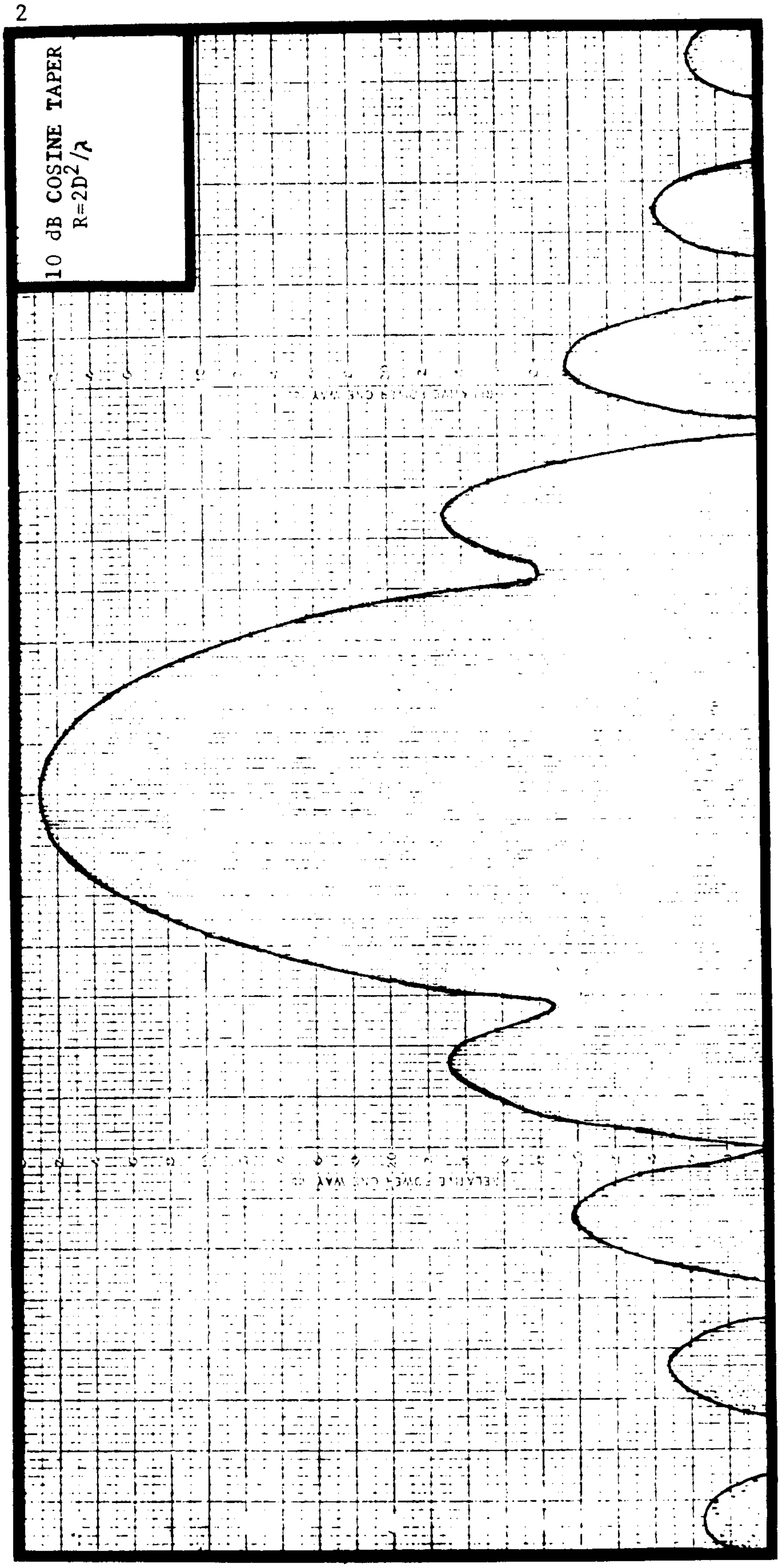

Figure A2.6 Calculated pattern of an antenna with a 10 dB Cosine feed illumination function. A phase error is assumed which corresponds to a test separation of $2D^2/\lambda$.

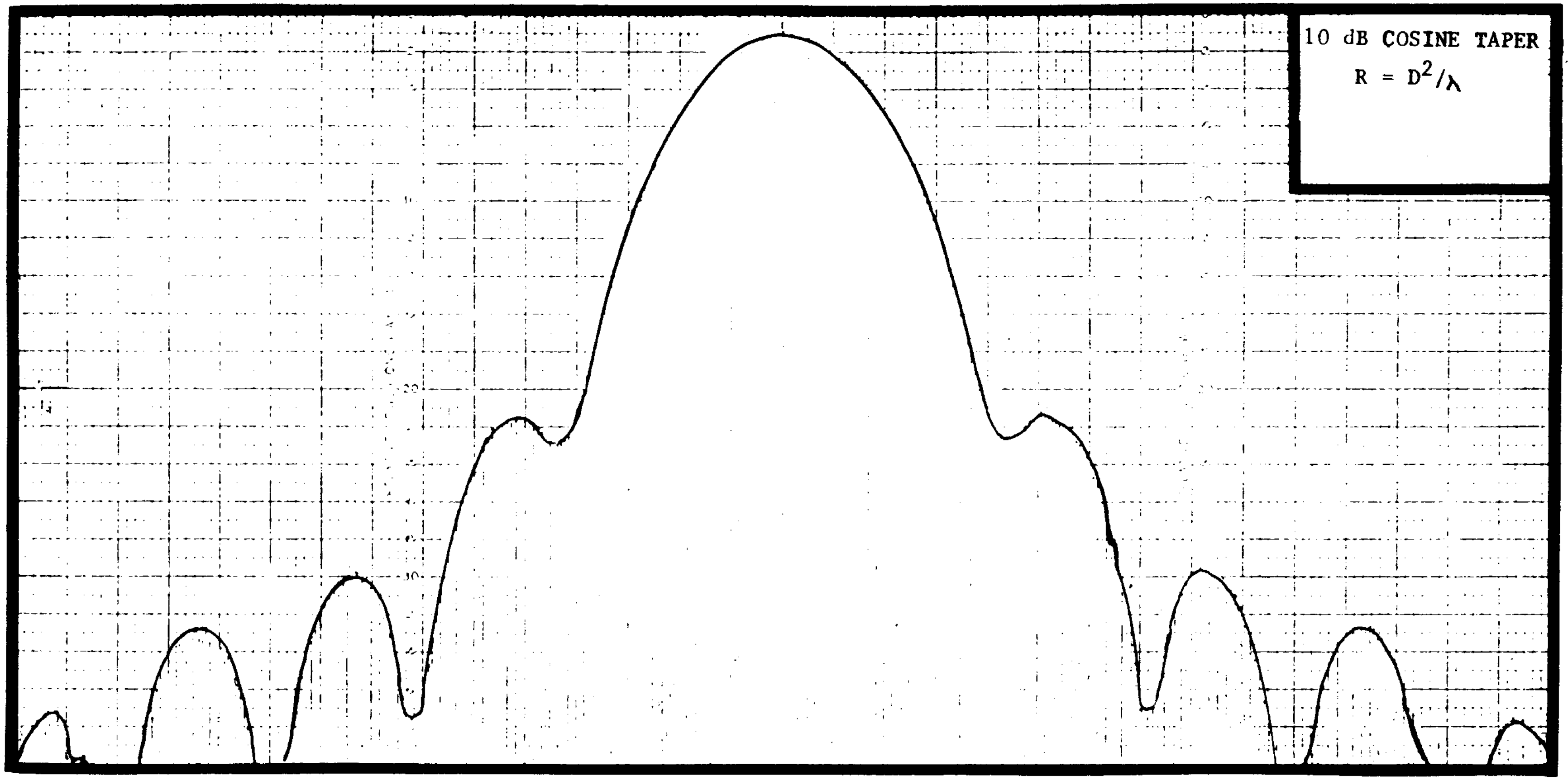

Figure A2.7 Calculated pattern of an antenna with a 10 dB Cosine feed illumination function. A phase error is assumed which corresponds to a test separation of D^2/λ.

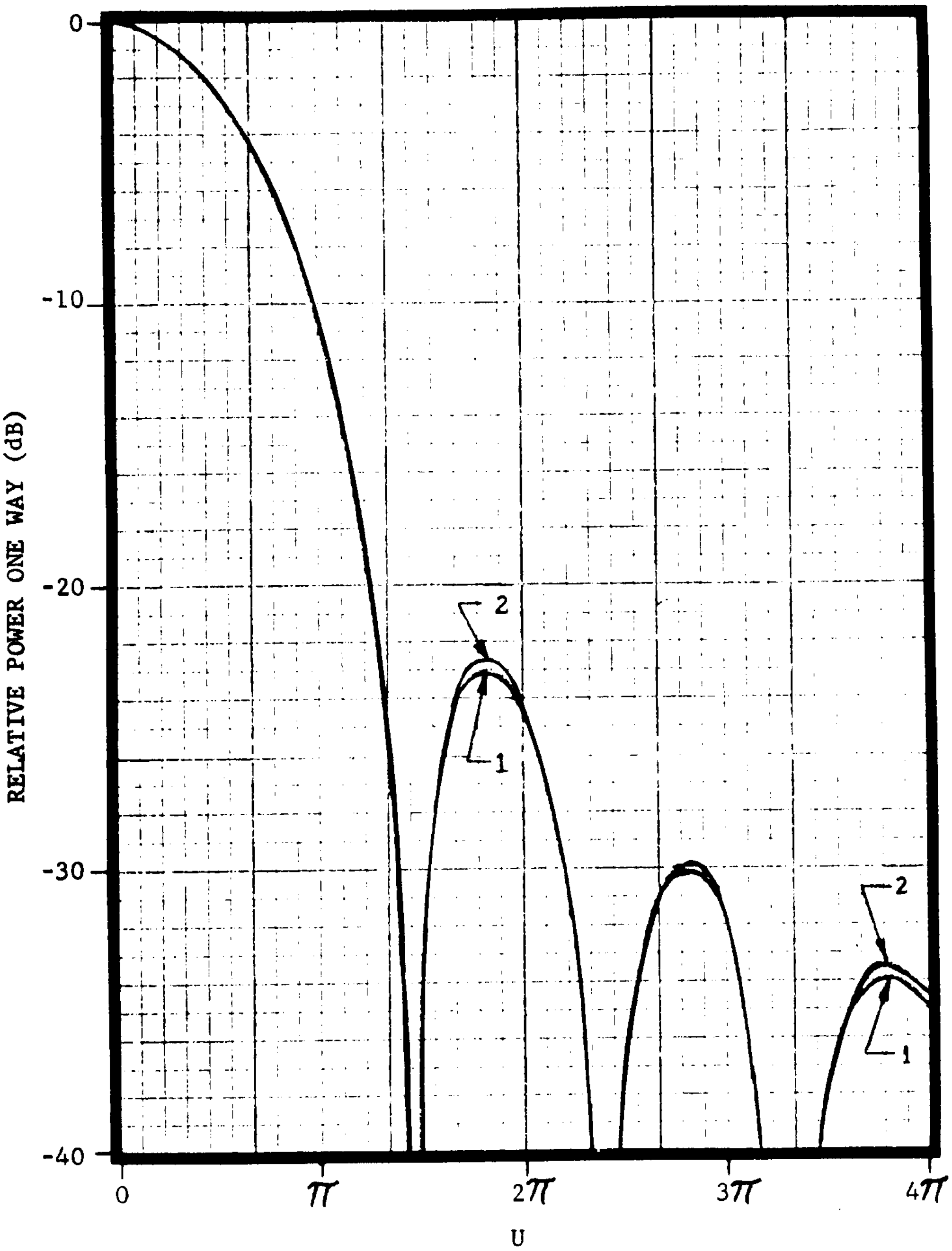

Figure A2.8 Calculated radiation patterns of a paraboloid with a 10 dB aperture illumination taper; (1) Measured with a 0.5 dB (Sin x)/x taper of the source antenna pattern, and (2) with no taper.

The decrease in measured gain caused by aperture taper is determined by the amount of taper and by the aperture illumination function of the antenna under test. For typical illumination functions, estimates of decrease in measured gain are 0.1 decibel for a 0.25 decibel taper and 0.04 decibel for a 0.1 decibel taper. A taper of less than approximately 0.01 decibel would be required to limit the decrease in gain to 0.01 decibel. A taper of 0.01 decibel would require a transmitting antenna 3-decibel beamdwidth of approximately 16 times the width of the aperture under test.

Calculated values of these decreases in gain as functions of both phase and amplitude tapers are presented in Tables A2.1 through A2.4 for four different aperture illumination functions. It can be seen in these tables that the correction factors are of sufficient consistency with illumination function that reasonably accurate corrections can be made to measured gain using these tables alone.

A criterion of 0.25 decibel is commonly employed for the limit of the amplitude taper over the test aperture. Calculated patterns reveal little distortion to the expected pattern as a result of small amplitude tapers in the illuminating field. The calculated pattern for the 0.25 dB taper is essentially the same as the one for the uniform field. However, if a source antenna is employed which is calculated to produce a taper of the field over the test aperture, it is essential that the transmitting antenna be directed such that the peak of its beam is centered on the antenna under test to prevent excessive and asymmetrical illumination taper with a resultant increase in the measuring error.

It is important to note that error from symmetrical amplitude taper within the accepted criterion of 0.25 decibel does not produce a defocusing type of error but a small modification of the measured side-lobe levels and an error in measured gain. Figure A2.9 shows the effect of both a 0.25 decibel amplitude taper produced by the directivity of a transmit antenna and a 22.5° phase taper produced by a range length of $2D^2/\lambda$. The antenna is truly characterized by the pattern shown in Figure A2.4. A gain reduction of 0.154 decibels would accompany this pattern distortion.

TABLE A2.1

**GAIN REDUCTION CORRECTIONS
CONSTANT ILLUMINATION FUNCTION**

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATING FIELD (SIN x)/x								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.224	.249	.276	.299	.325	.349	.469	.596	.720
2	.056	.080	.108	.130	.156	.181	.300	.427	.551
3	.025	.050	.076	.099	.125	.150	.269	.396	.520
4	.014	.139	.066	.089	.114	.139	.258	.386	.509
5	.009	.034	.061	.084	.109	.134	.253	.381	.504
6	.006	.031	.058	.081	.106	.131	.250	.378	.502
7	.005	.029	.056	.079	.105	.129	.249	.376	.500
8	.003	.028	.055	.078	.104	.128	.248	.375	.499
9	.003	.028	.054	.077	.103	.128	.247	.374	.498
10	.002	.027	.054	.077	.103	.127	.246	.374	.498
	0	.025	.052	.075	.100	.125	.244	.372	.495

TABLE A2.2
GAIN REDUCTION CORRECTIONS
10 dB COSINE FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATING FIELD (SIN x)/x)								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.206	.226	.248	.267	.288	.308	.405	.508	.609
2	.051	.072	.094	.112	.133	.154	.251	.355	.456
3	.023	.043	.065	.084	.105	.125	.223	.327	.428
4	.013	.033	.055	.074	.095	.115	.213	.317	.418
5	.008	.029	.051	.069	.090	.110	.208	.312	.413
6	.006	.026	.048	.067	.088	.108	.206	.310	.411
7.	.004	.024	.047	.065	.086	.106	.204	.308	.409
8	.003	.024	.046	.064	.085	.106	.203	.307	.408
9	.003	.023	.045	.064	.085	.105	.203	.307	.408
10	.002	.022	.044	.063	.084	.104	.202	.306	.407
	0	.020	.042	.061	.082	102	.200	.304	.405

TABLE A2.3
GAIN REDUCTION CORRECTIONS
10 dB $(1-\rho^2)$ ILLUMINATION FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATING FIELD (SIN x)/x								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.204	.224	.246	.265	.286	.307	.404	.509	.610
2	.051	.071	.093	.112	.134	.154	.252	.357	.459
3	.023	.043	.065	.084	.105	.126	.224	.329	.431
4	.127	.033	.055	.074	.096	.116	.214	.319	.421
5	.008	.029	.051	.070	.091	.111	.210	.315	.417
6	.006	.026	.048	.067	.089	.109	.207	.312	.414
7	.004	.025	.047	.066	.087	.107	.206	.311	.413
8	.003	.024	.046	.065	.086	.106	.205	.310	.412
9	.003	.023	.045	.064	.085	.106	.204	.309	.411
10	.002	.023	.045	.064	.085	.105	.204	.309	.411
	0	.020	.043	.062	.083	.103	.202	.307	.409

TABLE A2.4
GAIN REDUCTION CORRECTIONS
15 dB $(1-\rho^2)$ ILLUMINATION FUNCTION

RANGE LENGTH (D^2/λ)	DECIBEL AMPLITUDE TAPER OF ILLUMINATIN FIELD (SIN x)/x								
	0	.05	.1	.15	.2	.25	.5	.75	1.0
1	.188	.206	.227	.244	.263	.282	.373	.470	.564
2	.047	.066	.086	.104	.124	.142	.234	.331	.425
3	.021	.040	.060	.078	.098	.116	.208	.305	.399
4	.012	.031	.051	.069	.089	.107	.199	.296	.391
5	.007	.026	.047	.065	.084	.103	.195	.292	.386
6	.005	.024	.045	.062	.082	.101	.192	.290	.384
7	.004	.023	.034	.061	.081	.100	.191	.288	.383
8	.003	.022	.042	.060	.080	.099	.190	.287	.382
9	.002	.021	.042	.060	.079	.098	.189	.287	.381
10	.002	.021	.041	.059	.079	.098	.189	.286	.381
	0	.019	.040	.057	.077	.096	.187	.285	.379

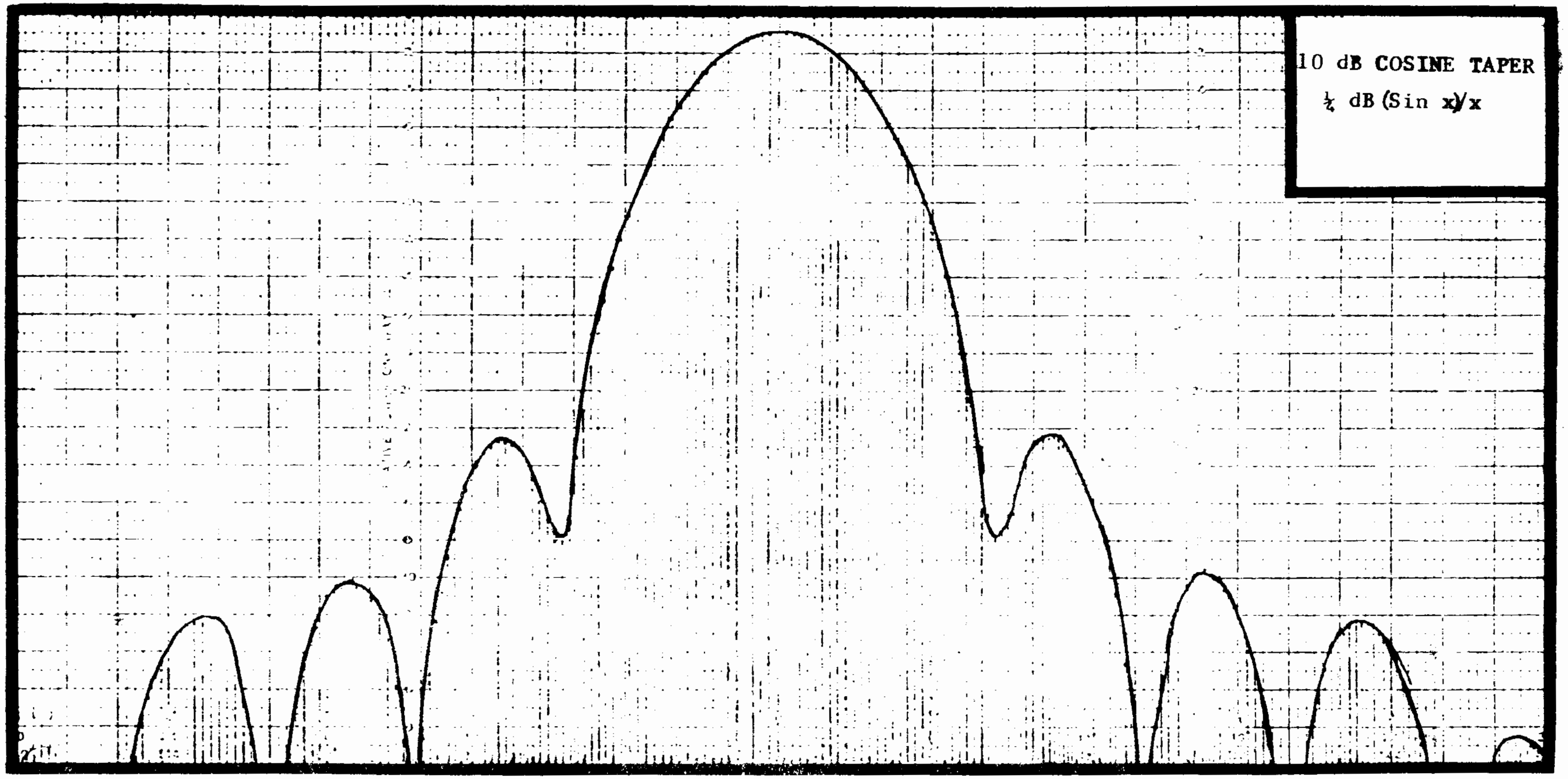

Figure A2.9 Calculated pattern of an antenna with a 10 dB Cosine feed illumination function. A phase taper corresponding to a test separation of $2D^2/\lambda$ and a 0.25 dB amplitude taper of the illuminating field characterized by a (Sin x)/x distribution are assumed.

The geometry of the elevated range is shown in Figure A2.10. Neglecting reflected energy from the range surface which will be discussed later, the amplitude taper across the test antenna is controlled by the beamwidth of the transmit antenna. The angle α subtended by the antenna under test, denoted by D in the figure is given by:

$$\alpha = 2 \tan^{-1} (D/2R_o) \doteq D/R_o \qquad (2.6)$$

since $R_o \gg D$. The approximate 1/4 dB beamwidth θ (.25) of typical

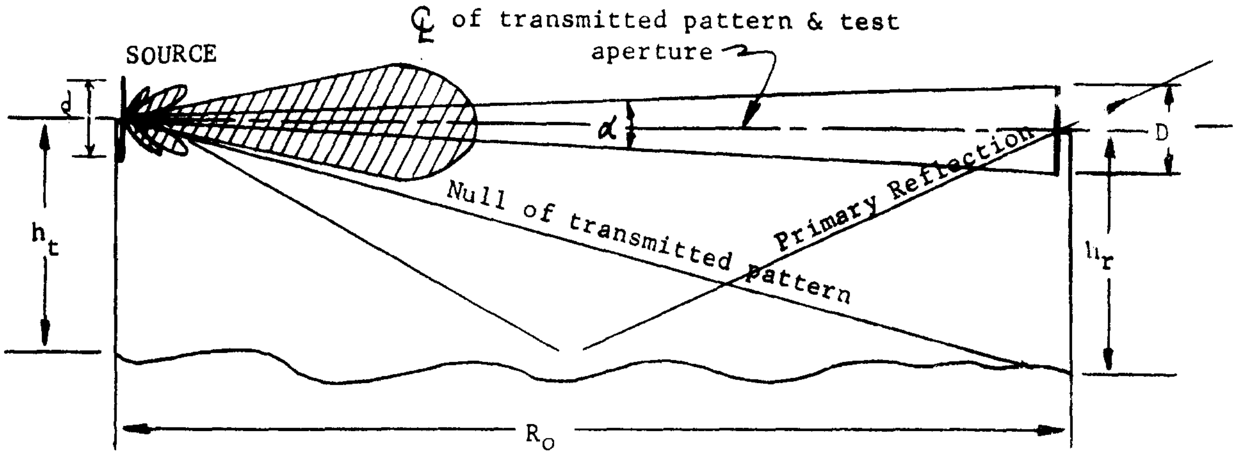

Figure A2.10 Elevated Antenna range geometry.

paraboloidal antennas commonly used for source antennas in the elevated mode is given by:

$$\theta\ (.25) \doteq 0.37\lambda/d, \qquad (2.7)$$

where d is the diameter of the source antenna and λ is the wavelength. It is readily seen that restricting the amplitude taper on the test antenna to a maximum of 0.25 dB is analogous to restricting the maximum diameter of the source antenna. Therefore:

$$0.37\lambda/d \lessgtr D/R_o \quad (2.8)$$

or

$$d_{max} = 0.37\lambda R_o/D. \quad (2.9)$$

A2.3 Extraneous Energy

The primary source of extraneous energy on an antenna range is reflections. A source of reflections that is common to all antenna ranges is the range surface. In the elevated mode of operation, the reflections from the vicinity of the range surface are minimized by clearing the vicinity of the range centerline of all obstacles such as trees, shrubs, etc.; selecting a source antenna of high directivity so as to allow only sidelobe energy to illuminate the range surface; and screening the surface from sidelobe energy by strategically placed conducting screens.

Refer to the geometry of Figure A2.10. Assume that the maximum amplitude taper of 0.25 dB exists across the aperture. The 0.25 dB beamwidth and main beam null separation for typical sin(x)/x microwave antenna patterns are related by

$$\theta\ (\text{NULL}) \doteq 8\,\theta\ (.25) \quad (2.10)$$

If the main lobe energy is restricted from the range surface, then the lower limit for the null of the transmitted pattern is the base of the receiver tower and:

$$\theta\ (\text{NULL}) \lessgtr 2 \tan^{-1} (h_r/R_o) \doteq 2h_r/R_o \quad (2.11)$$

since $R_o \gg h_r$. Combining this with equations (2.8), (2.9), and (2.10)

$$h_r \gtrless 4\ D \quad (2.12)$$

A practical design criterion for elevated test ranges is that the receive tower is 4.5 to 5 times the maximum dimension of the test aperture.

When R_o and h_r have been selected, the illumination criterion of equation (2.11) can be used to specify a minimum diameter of the source antenna.

$$\theta\ (\text{NULL}) \doteq 8\,\theta(.25) \doteq 8\,(.37\lambda/d) \leq 2h_r/R_o. \quad (2.13)$$

This requires that:

$$d_{min} = 1.5\ \lambda R_o/h_r. \quad (2.14)$$

Therefore a minimum source antenna diameter has been established due to the condition that only side-lobe energy be allowed to illuminate the ground. A maximum diameter was established to guarantee an acceptable amplitude taper across the test antenna. The restrictions on the size of the source antenna become:

$$1.5\,\lambda R_o/h_r \leq d \leq 0.37\,\lambda R_o/D. \qquad (2.15)$$

Many tests require suppression of range-surface reflections beyond that afforded by practical tower heights and source antenna sizes. Compliance with the criteria of equations (2.12) and (2.14) would probably result in an extraneous signal suppression of the order of -25 decibels relative to the direct-path signal level. The desired suppression can be calculated from the specified accuracy requirements by use of the expression

$$r = 20\log\left(1-10^{-a/20}\right) + G_D - G_R \qquad (2.16)$$

where

r is the ratio of reflected to direct-path signal levels in decibels ($r = 20\log E_R/E_D$),

a is the desired measurement accuracy in decibels,

G_D is the decibel gain of the test pattern in the direction of the direct-path signal, and

G_R is the decibel gain of the test pattern in the direction of the reflected signal.

It has been found that even over a very smooth surface, primary reflections can be additionally suppressed to levels less than -35 decibels through the use of strategically placed diffraction fences. Design values for the dimensions and locations of such fences can be calculated using Fresnel zone theory*, while final adjustments to the fence installations must be accomplished experimentally by means such as probe data of the field over the test aperture. While general criteria have not been developed which apply to all elevated range configurations, experience has shown that fences which screen approximately the first 20 Fresnel zones on the mean range surface will provide from -35 decibels to -40 decibels of suppression of range surface reflections when the terrain is nominally regular in cross-section and the previously discussed criteria are satisfied. It is necessary to arrange these fences so that little or no blockage of the main lobe of the transmitter pattern is caused by the fences. This precaution ensures that the residual variations in the field over the test aperture due to diffraction effects at the fences will represent a reasonable compromise with the level of reflected signal suppression.

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*Although Fresnel zones are rigorously defined on the basis of point source radiators, for practical antenna range geometries Fresnel zones for a point in the receiving aperture can be defined by regarding the transmitting antenna to be a point source located at the center-of-phase of its aperture.

A full development of Fresnel zone theory will not be presented here. The pertinent parameters of the Fresnel zones over a mean planar surface are the center, length, and width of the ellipse which describe the outer bound of a particular zone. These parameters can be calculated from the range geometry and the frequency of operation.*

In addition to providing line-of-sight clearance, low-level range surface illumination, and range surface screening via diffraction fences, the facility design should also ensure the clearance of all major extraneous reflecting or diffracting obstacles over the region within about 1.5 to 2 times the azimuthal main-lobe width of the transmitted pattern. Grading along the range boundaries can be performed to remove regions of possible wide-angle specular reflection into the test aperture.

* See, for example, Hollis, J. S., et al, Microwave Antenna Measurements, Section 14.2.4.

A2.3.1 Effects of Reflected Energy

Consider the case of a direct-path plane wave of amplitude E_d which is normally incident on the test aperture[12] as shown in Figure A2.11(a). Let an extraneous plane wave of amplitude E_r enter the aperture at an angle θ from the normal. At any given time, t, the phase of the direct wave is constant across the aperture and the direct-path field magnitude may be expressed in phasor notation as

$$E_d^* = E_d e^{j(\phi+\omega t)} \qquad (4.1)$$

where the asterisk denotes a complex quantity.

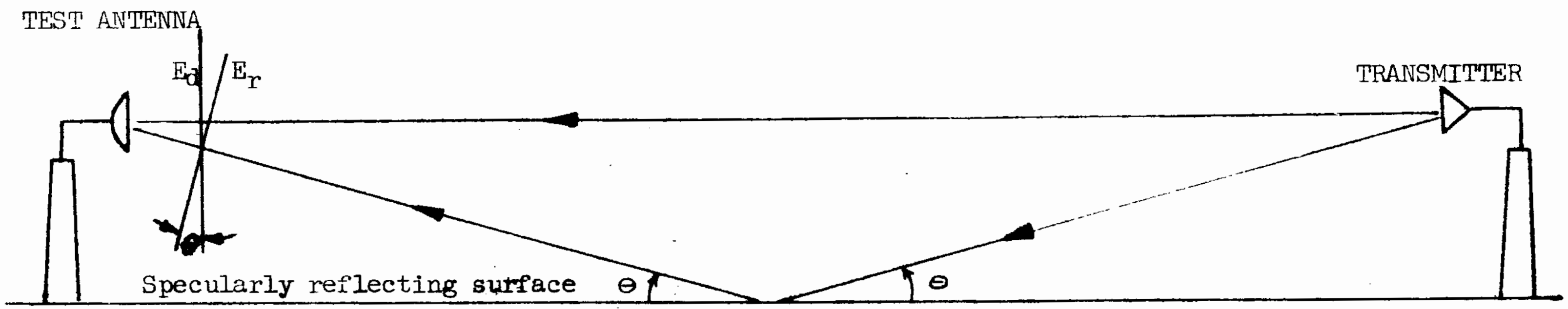
The phase of the postulated extraneous plane wave will vary across the aperture, so that the extraneous field magnitude is given by

$$E_r^* = E_r e^{j(2\pi x\sin\theta/\lambda + \phi' + \omega t)} \qquad (4.2)$$

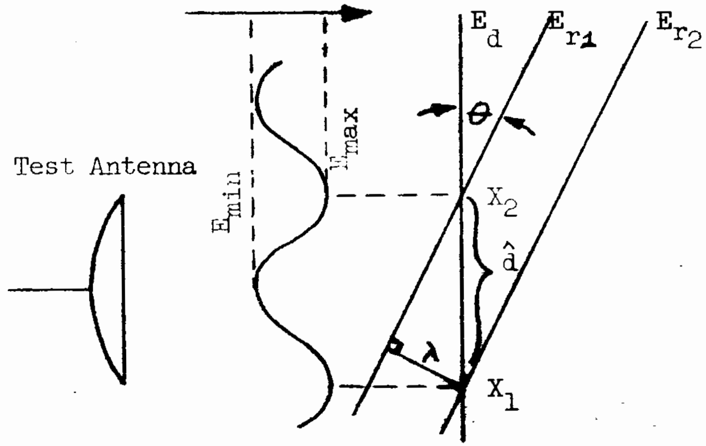
In (4.1) and (4.2), ϕ and ϕ' are constants, λ is the wavelength, and x is distance measured across the aperture parallel to the plane containing the directions of propagation of E_d^* and E_r^*. The magnitude of the total field in the aperture is that given by[13]

[12]The discussion here assumes a separation, R, between source and receiving antennas equal to or greater than $2D^2/\lambda$, where D is the maximum dimension of the receiving aperture. It is further assumed that the ratio D/R is small in comparison with the half-power beamwidth of the source antenna's pattern, so that the plane wave approximations are meaningful.

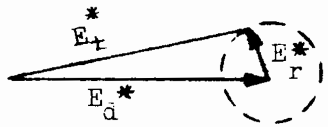
[13]This simplified example assumes that the polarizations of the reflected and direct-path waves are identical. While this is not strictly true, often the reflected wave will contain a large component with polarization identical to that of the direct-path wave.



(a) Reflected Wave Incident on a test aperture at an angle θ from the direction of propagation of the direct wave.



(b) Details of wave interference.



(c) Equivalent Phasor Representation.

Figure A2.11 Simplified sketch illustrating total aperture field variation caused by a single specularly reflected wave.

$$E_t{}^* = E_d{}^* + E_r{}^* = \left[E_d e^{j\phi} + E_r e^{j(2\pi x \sin\theta/\lambda + \phi')}\right] e^{j\omega t} \qquad (4.3)$$

Equation (4.3) describes a field with a sinusoidal variation in one dimension as sketched in Figure A2.11(b). In this figure, E_{r1} and E_{r2} represent two successive wavefronts of the reflected wave separated by λ, and E_d is a wavefront of the direct wave of identical phase. At points x_1 and x_2, the resultant amplitude is

$$E_{max} = E_d + E_r \qquad (4.4)$$

Halfway between these two points the waves are in phase opposition, and the resultant amplitude is

$$E_{min} = E_d - E_r \qquad (4.5)$$

The maximum amplitude variation within the aperture is thus given by

$$E = E_{max} - E_{min} = 2E_r \qquad (4.6)$$

Figure A2.12 is a graph of the magnitude of the resultant field amplitude ripple as a function of the ratio E_r/E_d.

The angle θ can be determined by

$$\theta = \sin^{-1}(\lambda/\hat{d}) \qquad (4.7)$$

where $\hat{d}$ is seen in Figure A2.11(b) to be the spatial period of the resulting interference pattern across the aperture.

The field in the aperture may also be represented as the sum of the two phasors, $E_d{}^*$ and $E_r{}^*$, as illustrated in Figure A2.11(c), where $E_r{}^*$ rotates relative to $E_d{}^*$. The phase of the field across the aperture will vary as the phase of the resultant of the direct-path and reflected phasors. The maximum phase variation for this plane wave case is then

$$\Delta\phi = 2 \sin^{-1} (E_r/E_d), \qquad (4.8)$$

where E_r is less than E_d.

The preceding example, although representing an idealized reflection, demonstrates the manner in which extraneous signals distort an otherwise planar wavefront. In a practical test situation, neither the direct nor the extraneous waves would be strictly planar, and there would be extraneous signal sources which could contribute to distortion of the incident field. For elevated ranges, however, for which the region around the range line-of-sight is relatively clear of reflecting objects, the primary source of extraneous signals is the range surface and the mathematical model developed above is a useful approximation to the physical situation.

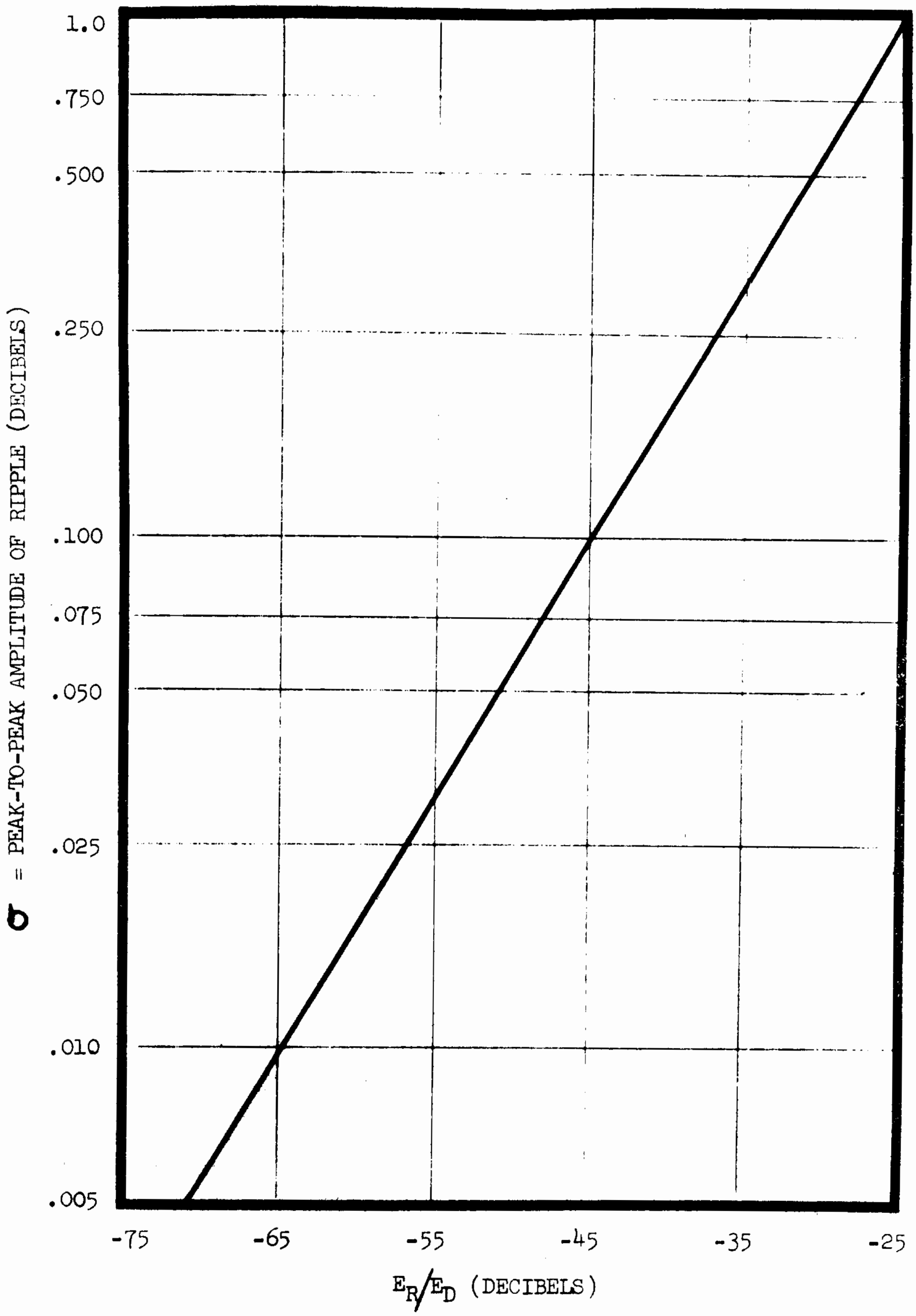


Figure A2.12 **Magnitude** of the **maximum** field perturbation as a function of **the relative** magnitude of the reflected signal.

A2.3.2 Range Fences 14

Energy which is incident on the range surface is reradiated in all directions; that energy which is reflected into the test aperture is a summation of wavelets reradiated from every point on the surface. If the surface is smooth in terms of the wavelength of the radiation, the energy striking the surface will be reradiated with a major lobe in the specular direction (angle of incidence equal to the angle of reflection) in accordance with Fermat's principle of stationary phase[15]. When the wavelength is sufficiently short and the range separation sufficiently long, reflection from a smooth range surface approaches the geometrical optics approximation in which all energy is reflected in the specular direction.

Reflection from a smooth surface can be analyzed by defining Fresnel zones on the surface similar to those defined in physical optics[16]. If the surface is planar, as well as smooth, the Fresnel zones produced by a point source radiator will be defined by a family of expanding ellipses[17]. Conventionally the zones are identified by numbering them consecutively, beginning with the inner zone. The specular point falls within the first Fresnel zone and, for typical elevated ranges, is near the geometrical center of the first zone. Although reflected energy from the entire

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[14]For further discussion of this topic see:
T. J. Lyon, et al, "Evaluation of the NASA-KSC-MILA RF Boresight Test Facility at X-Band and S-Band," FINAL REPORT Contract No. NAS10-2103, Scientific-Atlanta, Inc., N-67-13025.
J. S. Hollis, et al, "Investigation of Precision Antenna Pattern Recording and Display Techniques, Phase II," FINAL REPORT, Contract No. AF30(602)-3425, Scientific-Atlanta, Inc., AD630214.

[15]S. Silver, Microwave Antenna Theory and Design, Radiation Laboratory Series, Vol. 12, McGraw-Hill Book Co., pp. 119-128, 1950.

[16]See, for example, D. E. Kerr, Propagation of Short Radio Waves, Radiation Laboratory Series, Vol. 13, McGraw-Hill, pp. 411-418, 1951.

[17]It should be noted that Fresnel zones, as used here, are defined in terms of isotropic radiators and receivers. Such zones differ considerably from the half-period zones which could be defined in terms of the actual directive source and test antennas. Excellent results have been achieved on the basis of isotropic antenna analysis, however, and further complication of the mathematics appears to be unnecessary in most cases.

range surface contributes to the extraneous signal level at the test aperture, the level can be reduced considerably by blocking reflected energy from the first several Fresnel zones. Reduction of the relative extraneous signal level at the test aperture by approximately 10 to 20 decibels is achievable by blocking reflections from at least the first 20 zones, for typical elevated antenna range problems[18]. This blockage is easily achieved through the use of conducting fences placed on the range surface over the central Fresnel zones[19].

In choosing a fence configuration for an elevated range, consideration must be given to the problem of interference due to diffraction over the fence edges. The energy which reaches the test aperture is the summation of contributions from all points on a spherical wavefront encompassing the source, as described in Huygen's principle[20, 21, 22]. Thus, blockage of any portion of the transmitted wavefront results, through the process of diffraction, in a perturbation of the energy incident on the test aperture. The nature of the diffraction disturbance can be illustrated with the simplified example of diffraction over an infinite, straight, absorbing edge which is placed between a radiator and a plane AB, as shown in Figure A2.13. It is desired to know the magnitude of the field at a point P, which lies in the plane AB. The absorbing half-plane blocks a portion of the wavefront; the field at P is determined by applying Huygen's principle to sum the contributions at P from the remainder of the wavefront. The normalized field at P can be approximated by[23]

$$\frac{E}{E_0} = \left| \frac{1}{\sqrt{2}} \int_{v_0}^{\infty} e^{-j(\pi v^2/2)}\, dv \right|, \qquad (4.9)$$

$$v = u \left[\frac{2(d_1 + d_2)}{\lambda d_1 \; d_2} \right]^{\frac{1}{2}} \qquad (4.10)$$

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[18]Lyon, et al, op cit.

[19]Ideally, absorbing fences are preferred to eliminate the possibility of reflections from the fences resulting in measurement interference; if the fences are properly designed, however, interference from this source is often negligible.

[20]E. C. Jordan, Electromagnetic Waves and Radiating Systems, Prentice-Hall pp. 572-577, 1950.

[21]Bruno Rossi, Optics, Addison-Wesley, Chapter 4, 1957.

[22]R. S. Longhurst, Geometrical and Physical Optics, Chapter 10, 1957.

[23]E. C. Jordan, op cit.

and where E_o is the field which would result from the unobstructed wave, u is the arc length measured along the wavefront from the line TP, v_o corresponds to the point of the wavefront which inter - sects the top of the obstruction, d_1 is the radius of the wavefront, and d_2 is the distance from the wavefront to P.

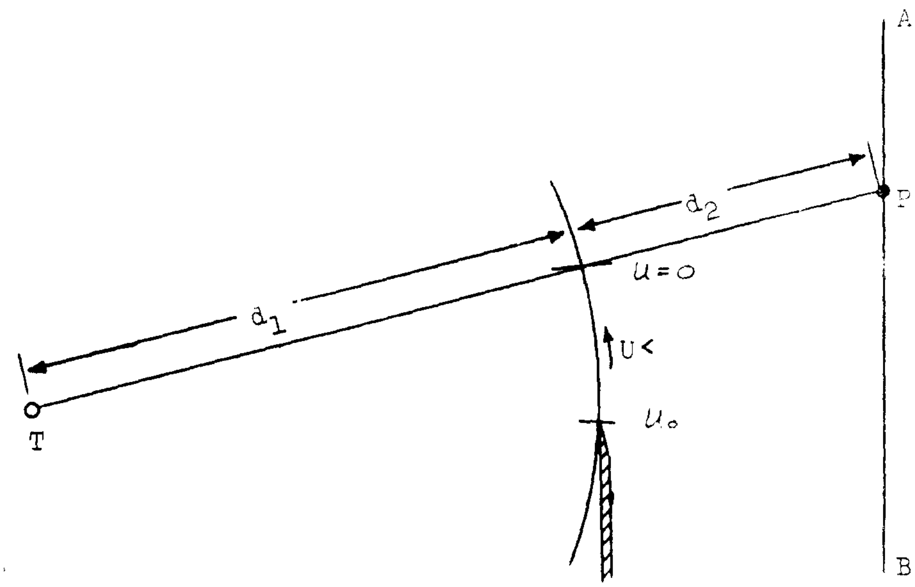

Figure A2.13 Edge Diffraction Geometry.

A plot of equation (4.9) is reproduced in Figure A2.14. Positive values of v_o correspond to field points in the shadow region; negative values correspond to field points in the region of direct illumination. The resultant field magnitude in the direct illumination region varies in an oscillatory manner with the location of the observation point. This disturbance is essentially equivalent to that which would be caused by a coherent cylindrical wavefront emanating from the diffracting edge which systematically interferes with the spherical wavefront of the unobstructed signal.

The foregoing example is obviously idealized. Clearly, an infinite, perfectly-absorbing half-plane is not physically realizable; it has been shown, however, that diffraction patterns for finite, reflecting edges are similar to the theoretical pattern of Figure A2.14. [24, 25].

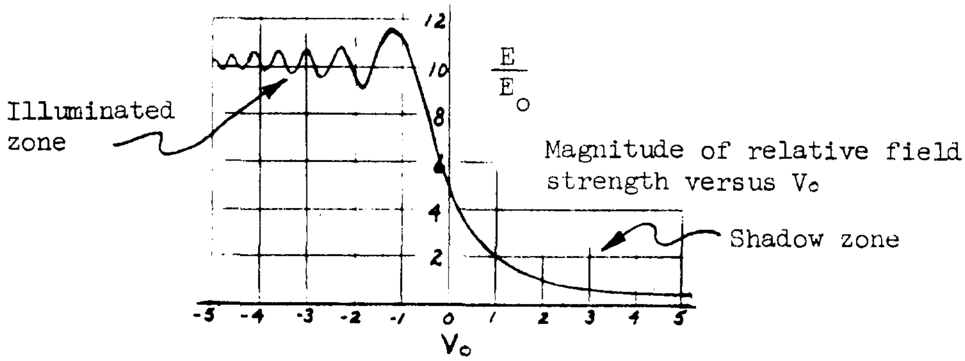

Figure A2.14 Field amplitude due to diffraction at an edge.

Diffraction disturbances can be reduced by increasing the clearance of the range line-of-sight above the fences and by utilizing the directivity of the source antenna to minimize the energy blocked by the fences. A desirable design goal is to provide for sufficient clearance over each fence to allow passage of the entire principal lobe of the radiated energy distribution. Further reduction can be achieved, if required, by shaping the tops of the fences (with serrations, for example) to destroy the phase coherence of the diffracted energy.

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[24] H. Martinides, "The Screening Effect of Obstacles With a Straight Edge," Goddard Space Flight Center, N65-33504-04, 1965, p.5.

[25] T. J. Lyon, et al, op cit.

A2.4 Probe Data Requirements

Paragraph 4.7 establishes requirements for the electromagnetic performance of the test range(s) used by the Contractor to verify the electrical characteristics of the antennas. The electromagnetic performance of the test range(s) will be verified by recording the probe data described below and reporting these results in the Contractor's range validation report. The probe data must meet the requirements established below prior to acceptance of the range(s) as suitable for the testing required by this contract.

A probe mechanism similar to that shown in Figure A2.15 shall be used for the field measurements required below. The 3-dB elevation and azimuth beamwidths of probe shall be no less than 30 degrees. The elevation beamwidth of the probe shall not be less than 2 $\tan^{-1}(4h_t/Ro)$ radians where h_t and Ro are defined in Figure A2.10.

All probe data and related requirements described below are necessary at both 1030 MHz and 1090 MHz.

A2.4.1 Probe Measurements Over Test Aperture

The plane normal to the line of sight from the source antenna to the test antenna and passing thru the geometrical center of the test antenna aperture when this aperture is also normal to the line of sight is the test aperture plane. The test aperture is the minimum region within the test aperture plane that includes all projections(parallel to the above mentioned line of sight) of the test antenna aperture over all angles of elevation tilt and azimuth rotation employed during antenna testing.

The following probe data and associated performance are required.

(1) With the source antenna oriented to transmit vertically polarized energy and the field probe antenna oriented to receive vertically polarized energy along the line of sight to the source antenna, record the detected signal from the probe antenna as it is moved across the horizontal center line of the test aperture. Repeat this recording with the probe moving along both diagonals across the test aperture (through the center of the test aperture) and along the entire vertical center line of the test aperture.

(a)The amplitude taper, for any recording across the entire test aperture, shall be less than 0.25 dB as determined by measuring the difference between the amplitudes of the maximum and minimum points of the taper.

(b)The amplitude taper shall be centered on the test aperture in the sense that the peak of the taper shall be centered on the test aperture and, for any one recording, the taper levels at the edges of the test aperture shall be the same to within 0.10 dB.

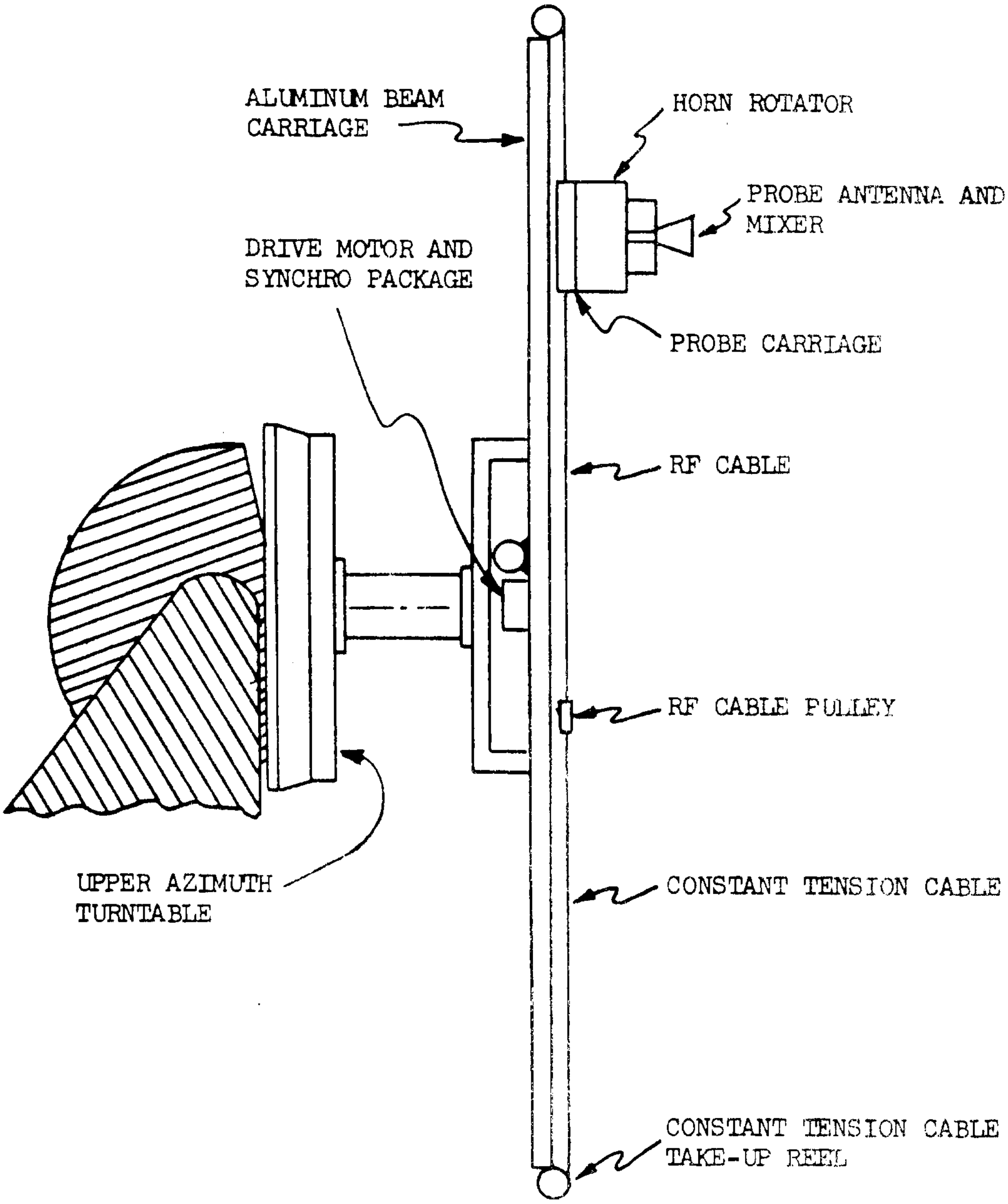

Figure A2.15 Schematic diagram of field probe mechanism.

(c) The maximum peak-to-valley variation between any maximum and the adjacent minimum shall be less than 0.35 dB when the effects of taper have been accounted for.

(d) The maximum peak-to-valley excursion of any recording across the entire test aperture shall be less than 0.65 dB.

(2) Repeat the recordings of (1) above with the source and probe antennas oriented for horizontally polarized energy. These data shall meet the requirements of (1a) through (1d) above.

(3) With the source antenna oriented to transmit vertically polarized energy and the field probe oriented to receive horizontally polarized energy, record the detected signal of the probe antenna as it is moved across the test aperture along the horizontal center line. Reorient the probe antenna to receive vertically polarized energy and insert 35 dB attenuation in the path of the detected signal. Record the attenuated probe signal as the probe is moved across the test aperture along the horizontal center line such that the received signal strength for a given probe position appears directly above the cross-polarized level previously recorded. The signal level in the first case shall not exceed the signal level recorded for the later case. Repeat the recordings with the probe moved along both diagonals and the vertical center line across the entire test aperture. For all recordings, the horizontally polarized signal level shall not exceed the level of the attenuated vertically polarized signal.

(4) Repeat the recordings of (3) above with the source antenna oriented to transmit horizontally polarized energy and the probe antenna oriented for alternately recording the vertically polarized signal and the attenuated horizontally polarized signal. For all recordings, the vertically polarized signal level shall not exceed the level of the attenuated horizontally polarized signal.

A2.4.2 Probe Measurement Over 360 Degrees Azimuth

(1) Orient the source antenna to transmit vertically polarized energy and rotate the probe carriage mount so that the axis of rotation of the carriage is vertical. Face the probe antenna toward the source and orient the probe to receive vertically polarized energy. Position the probe carriage vertically so that it is within the test aperture. Move the probe antenna horizontally on the field probe mechanism to a point approximately 5 wavelengths out from the axis of rotation. Rotate the probe carriage 360 degrees in azimuth and record the detected signal. Move the probe antenna approximately one wavelength horizontally inward toward the axis of rotation. Rotate the probe carriage 360 dgrees in a manner that overlays the same azimuth angles precisely over those previously recorded. Continue this procedure moving the probe antenna in approximately one wavelength steps each time until it has been moved horizontally to the opposite side of the axis of rotation by approximately

five wavelengths. The overlayed patterns are those of the probe antenna taken at various horizontal positions each side of the axis of mount rotation. The amplitude variation of these patterns at each angle of rotation is an indication of thereflected energy. The actual pattern of the probe antenna is the mid-power position of the overlayed patterns. The relative reflected power arriving from the azimuth Θ shall be estimated as:

$$\frac{E_r}{E_d}(\Theta) = 20 \log_{10} \frac{10^{\sigma/20} - 1}{10^{\sigma/20} + 1} + G(\Theta) \quad dB$$

Where σ is the measured maximum-to-minimum amplitude variation (in dB) at the angle Θ and $G(\Theta)$ is the gain (in dB) of the probe antenna (with respect to the peak of the probe pattern) at the azimuth angle Θ. At all azimuth angles $0^\circ \leq \Theta < 360^\circ$, the estimated relative reflected power shall be less than -35 dB.

(2) Orient the source and probe antenna for horizontally polarized energy and repeat the measurements and associated computations of (1) above. At all azimuth angles, $0^\circ \leq \Theta \leq 360^\circ$, the estimated relative reflected power shall be less than -35 dB.

(3) With the source antenna oriented to transmit vertically polarized energy and the probe antenna oriented to receive horizontally polarized energy, position the probe carriage as in (1) above and move the probe horizontally to a distance of at least five feet from the axis of rotation. Rotate the probe carriage 360 degrees in azimuth and record the detected signal. Reorient the probe antenna to receive vertically polarized energy and insert 35 dB attenuation in the path of the detected signal. Record the attenuated signal of the probe antenna at the peak of the beam. The signal recorded in the first case over the complete 360 degrees shall not exceed the signal level recorded for the later case., This test measures cross polarization throughout 360 degrees of azimuth that can affect the accuracy of the cross polarization measurement of the test antenna.

(4) Repeat the measurement of (3) above with the source antenna oriented to transmit horizontally polarized energy and the probe antenna oriented first for vertically polarized energy (record probe signal over 360° azimuth) and then for horizontally polarized energy (record attenuated probe signal at the peak of the probe beam). The vertically polarized signal shall not exceed the attenuated horizontally polarized signal level over 360 degrees in azimuth.